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Pollution Abatement and By-Product Recovery in Shellfish and Fisheries Processing

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16. Abstract 70 million pounds of seafood wastes, mainly from crab, salmon, and shrimp fishing, containing 22.1 million pounds of COD were discharged to Kodiak Harbor in 1970. A private firm was engaged to develop a plan to permit development of beneficial uses for the wastes while concurrently reducing the pollutional load on the harbor. The plan which was developed included collection and transportation of the waste to a central processing site on Near Island for by-product recovery. Shellfish wastes would be extracted with dilute alkali to yield a high quality protein and a chitin-calcium carbonate residue, the former to be used as pet food additives or for industrial applications, and the latter to be exported for conversion to chitin and derived products or used in Alaska as a soil liming and fertilizer material. Fish wastes would also be extracted to yield a concentrated protein product similar to fish solubles oil and bone meal. Market surveys indicated that sufficient markets for the by-products existed to allow the system to pay for itself, with all charges to the industry being saved for rebuilding the plant in 7 years. The proposed plan would accomplish a 70% reduction in the present pollutional load and ~~also~~ provide valuable by-products as well. (Lowry-Texas)

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POLLUTION ABATEMENT AND BY-PRODUCT RECOVERY IN SHELLFISH AND FISHERIES PROCESSING

by

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for the

ENVIRONMENTAL PROTECTION AGENCY

Project # 12130FJQ
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June 1971

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ABSTRACT

Laboratory and pilot plant studies show that utilizable by-products can be obtained from shell fish wastes produced at Kodiak, Alaska. Alkali extraction of the contained protein leaves a matrix of chitin and calcium carbonate ($CaCO_3$). The chitin-$CaCO_3$ matrix can be converted chemically into its components.

Other fishery wastes found at Kodiak; salmon waste and small fish associated with shrimp can be liquified by alkali treatment, partially neutralized with acid, and converted into oil, bone meal and 50% solubles.

The economics and pollution abatement capabilities of a proposed plant are discussed. The construction and operation of this plant would reduce the yearly pollution load from the present 22.1 million lbs per year of C.O.D. being dumped into Kodiak Harbor to 6.6 million lbs per year of C.O.D.

Preliminary designs are submitted for the implementation of this process, together with indicated markets and plan of operation.

This report was submitted in fulfillment of Project Number 11060 FJQ, under the (partial) sponsorship of the Water Quality Office, Environmental Protection Agency.

CONTENTS

Section		Page
I	Conclusions	1
II	Recommendations	3
III	Introduction	5
IV	The Present Pollution Problem	9
V	Process Description	19
VI	Pollution Abatement	23
VII	Laboratory Investigations	27
VIII	Markets	51
IX	Proposed Facilities	55
X	Economic Considerations	65
XI	Pro Forma Business Structure	71
XII	Alternate Disposal Methods	73
XIII	In-House Improvements at Processing Plants	75
XIV	Acknowledgments	77
XV	References	79
XVI	Publications	81
XVII	Appendix	83

FIGURES

No.		Page
1	Map: State of Alaska	6
2	Processing Plant Locations at Kodiak Harbor	10
3	Shrimp Production at Kodiak, Alaska	13
4	Composition of Wastes by Percent	28
5	Extraction Rates for Shellfish Wastes	36
6	Oxygen Consumption by Shellfish Waste	40
7	Map: Location and Topography - Near Island	56
8	Dock and Trestle for the Proposed By-Product Recovery Plant	58
9	Plan: By-Product Recovery Plant Process Building	59
10	Schematic Flow Diagram - Scrap Fish from Shrimp Processors, Crab Butchering Waste and Salmon Fisheries Waste, Processing Unit	61
11	Schematic Flow Diagram - Shrimp Waste Processing Unit	62
12	Schematic Flow Diagram - Crab Picking Line Waste Processing Unit	64

TABLES

No.		Page
1	Crab Production in 1970 for the Kodiak Area	14
2	1970 Salmon Production at Kodiak	17
3	Pollution Load	23
4	Water Usage by Processors at Kodiak	24
5	Amino Acid Composition of Spray Dried Shellfish Waste Proteins	33
6	C.O.D. Values of Shellfish Waste	39
7	Waste Distribution in Shrimp Processing A. Raw Peeling	42
8	Waste Distribution in Shrimp Processing B. Peeling after Steaming	43
9	Cooking Whole Crab	45
10	Live Butchered Crab	46
11	Sales/Year - Income from Disposal Fee	67
12	Yearly Operating Expenses	68
13	Plant Investment - June 1971 Prices	69

SECTION I

CONCLUSIONS

1. The present pollution load discharged to Kodiak Harbor as wastes from shellfish and fish processing is about 22.1 million lbs of C. O. D. per year. This is roughly equivalent to the domestic wastes from a city of 250,000 population.

2. A plan for collection and treatment of solid wastes to produce marketable by-products has been developed.

Wastes would be collected in barges and transported to a site on Near Island for by-product recovery. Shellfish wastes would be extracted with dilute alkali to yield a high quality protein and a chitin-$CaCO_3$ residue as products. The protein would be marketable as a pet food additive or for industrial applications. The chitin-$CaCO_3$ residue could be exported for conversion to chitin and derived products or could be used in Alaska as a soil liming and fertilizer material.

Fish wastes would also be alkali extracted to yield a concentrated protein product similar to fish solubles, oil and bone meal.

3. The proposed plan would accomplish a 70% reduction in the present pollution load and is shown to be practical and economically sound.

4. Any rational plan for complete pollution abatement by secondary treatment of liquid wastes would require prior separation and disposal of solid wastes.

SECTION II

RECOMMENDATIONS

1. A pollution control district comprising all of the seafood processing plants should be established.

2. A board of directors should be elected and managements should be appointed.

3. A decision to construct a by-product recovery plant for solid wastes, using processes developed in this study, should be made.

4. A plan for financing the enterprise should be developed.

5. Consultants should be retained for design, construction and operation of the facility and for marketing of its products.

6. A schedule for construction of the facility should be prepared to comply with Federal and State of Alaska regulations.

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SECTION III

INTRODUCTION

The City of Kodiak, Alaska, located on the northeast shore of Kodiak Island (Figure 1), has been an important center for fish and shellfish processing for many years. Starting in 1963, with development of the Alaska King crab fishery, very rapid expansion of operations in Kodiak occurred. Also a serious pollution problem developed.

Processing plants, now numbering 15, are spread over 2 miles of waterfront and are generally located on docks or moored vessels. Usual practice is to discharge all wastes into harbor waters adjacent to the plant. In 1967 about 50 million lbs of King crab waste were so handled. Since then the King crab fishery has declined to 20% of its peak but shrimp processing has increased to the extent that over 70 million lbs of waste were discharged into Kodiak Harbor in 1970.

Food, Chemical and Research Laboratories, Inc. became acquainted with the Kodiak pollution problem in 1966 as a result of discussions with principals in the major processing companies for which the Laboratories performed quality control services on products shipped via Seattle. Several of these companies had, in the past, considered recovery of solid wastes from shellfish processing by production of a dried crude shellfish meal.

Economic analysis of costs and markets for such products led to the conclusion that production costs in Kodiak and freight to Puget Sound ports or other possible markets would be prohibitive.

As an alternate, Food, Chemical and Research Laboratories, Inc. independently explored the possibilities of upgrading shellfish waste by separating it into its principal components; protein, chitin and calcium salts. It was found that a protein of high nutritional value could be extracted from the shell by mild alkali treatment and that chitin, after conversion to chitosan, was useful as a coagulant and coagulant-aid in water and waste treatment. Possible return from the waste was thus increased from about $20 per ton for dry crab meal F.O.B. Kodiak to perhaps $200 per ton (500 lbs protein at $0.15, 500 lbs chitin at $0.25).

One of the King crab producers, Pan Alaska Fisheries, supported additional work on the proposed process and further studies were supported by contracts from the U. S. Bureau of Commercial Fisheries,

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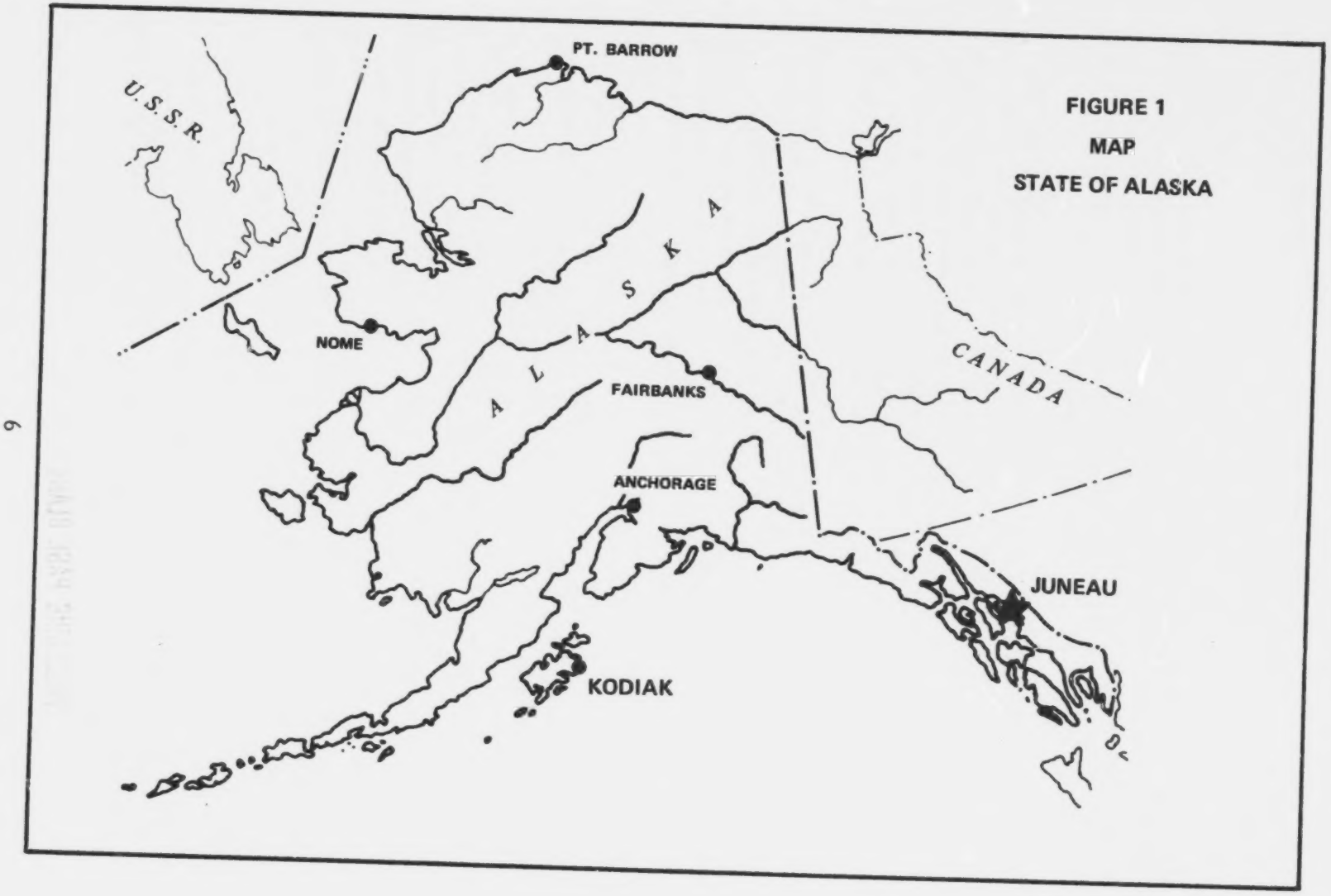


FIGURE 1

MAP

STATE OF ALASKA

now National Marine Fisheries Service. These studies concluded that extraction of protein from shellfish waste was economically practical at Kodiak but that further processing of the residue, chitin and $CaCO_3$ to obtain chitin should be done in areas where low cost hydrochloric acid (HCl) was available. Alaska markets for the residue as a soil liming agent and fertilizer appeared practical as an alternate disposal.

In 1969 the severity of the pollution problem at Kodiak and the imminent need to comply with Federal and State of Alaska laws regarding waste discharges prompted application to the Water Quality Office, Environmental Protection Agency for a research, development and demonstration grant to the City of Kodiak. Objectives stated in the application were:

a. To design and construct a facility to effect abatement of primary pollution from shellfish waste in Kodiak Harbor.

b. To demonstrate a shellfish by-product recovery process for conversion of waste. The process may also be applicable in other processing localities.

c. To develop in-house measures at shellfish processing plants for reduction of secondary pollution levels.

The plan of work for the project initially was divided into seven tasks as follows:

Task 1 - An engineering survey at Kodiak to:

a. Determine character, extent and distribution of pollution loads.

b. Obtain all basic data needed for preliminary design of waste collection and recovery facility including optimum site location, collection equipment and procedures, site improvements, probable costs for fuel, labor, freight, power, water, etc.

c. Review operating practices and facilities at individual processing plants to determine possibilities for in-house improvements and changes needed to permit handling of wastes by the recovery facility.

Task 2 - Pilot plant and chemical studies at Seattle to obtain design parameters for the recovery facility and to characterize wastes and possible products.

Task 3 - A market development study to determine acceptability of products for possible end uses, potential sales volumes and prices.

Task 4 - Preparation of a Pre-construction Summary Report.

Task 5 - Engineering Design of Facilities.

Task 6 - Construction of Facilities.

Task 7 - Operation of system for 1 year with demonstration of pollution abatement, economic feasibility and training of personnel for continuation of operation.

On April 6, 1970, Tasks 1, 2 and 4 of the application were funded through a grant to the City of Kodiak with CRESA, a joint venture between Food, Chemical and Research Laboratories, Inc. and Engineering-Science of Alaska, as contractor. Task 3 was disallowed as not within the allowable scope of EPA support. Tasks 5, 6 and 7 were deferred pending completion of Task 4 and approval.

SECTION IV

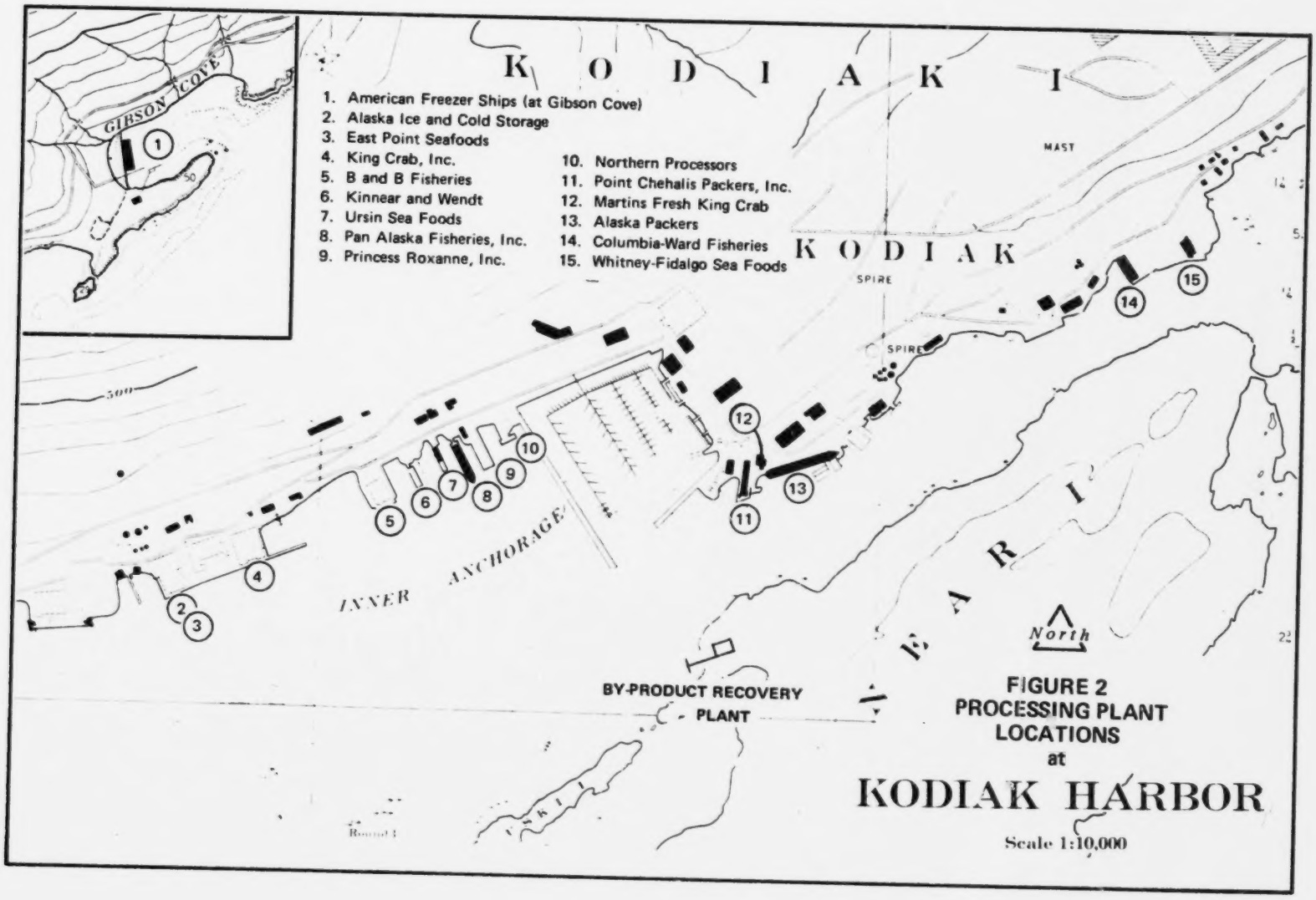
THE PRESENT POLLUTION PROBLEM

Plant Locations

Figure 2 is a map of Kodiak Harbor showing locations of processing plants. Starting at the southwest end of the harbor, these are:

1. American Freezerships (at Gibson Cove)
2. Alaska Ice and Cold Storage Inc.
3. East Point Seafoods Co.
4. King Crab Inc.
5. B and B Fisheries
6. Kinnear and Wendt Inc.
7. Ursin Seafoods, Inc.
8. Pan Alaska Fisheries, Inc.
9. Roxanne Fisheries, Inc.
10. Northern Processors, Inc.
11. Point Chehalis Packers, Inc.
12. Martins King Crab
13. Alaska Packers Association
14. Columbia-Ward Fisheries
15. Whitney-Fidalgo Seafoods, Inc.

The plant at Gibson Cove is on a converted ferry. The ferry is moored below a rocky hill that makes land access difficult. The site is about 1 mile southwest of the next plant in the line. Plants 2 through 10 are along a 1/2 mile stretch of waterfront southwest of the breakwater for the small boat harbor. There are three plants,


GIBSON COVE
1. American Freezer Ships (at Gibson Cove)
2. Alaska Ice and Cold Storage
3. East Point Seafoods
4. King Crab, Inc.
5. B and B Fisheries
6. Kinnear and Wendt
7. Ursin Sea Foods
8. Pan Alaska Fisheries, Inc.
9. Princess Roxanne, Inc.
10. Northern Processors
11. Point Chehalis Packers, Inc.
12. Martins Fresh King Crab
13. Alaska Packers
14. Columbia-Ward Fisheries
15. Whitney-Fidalgo Sea Foods
K O D I A K I
K O D I A K
MAST
SPIRE
SPIRE
INNER ANCHORAGE
BEAR
North
BY-PRODUCT RECOVERY PLANT
FIGURE 2
PROCESSING PLANT LOCATIONS
at
KODIAK HARBOR
Scale 1:10,000

11 through 13, just northeast of the boat harbor and the last two are about a 1/2 mile farther to the northeast.

Operations in the processing plants differ widely as to species handled, size and type of pack. Some operations are more seasonal than others so that the pollution load varies widely throughout the year as to character, volume and distribution.

Shrimp Processing

Alaska shrimp are smaller than shrimp caught in most other areas with counts of 350 to 450 per lb on a peeled weight basis. Processing consists of sorting out small scrap fish and debris (caught in the trawls with the shrimp) and mechanical peeling with or without a quick steam precook. The precook requirement depends on the type of peeler used.

After peeling and washing the shrimp are packed for freezing or canning.

Since 1969 shrimp processing has been by far the major operation at Kodiak and its relative importance is still increasing in 1971. There are now six shrimp processors, all in the group southwest of the boat harbor with major producers at the southwest end of the line. While both canning and freezing operations are conducted, from a pollution standpoint there is little difference in the character or amount of waste generated as a fraction of the live weight. All plants use mechanical peelers which typically recover about 18% of the live weight as salable product leaving 82% as waste. Water usage averages about 7.5 gals. per lb of live weight processed but varies from 5 to 10 gals. depending on peeler design and operation and the production rate.

To evaluate the pollution load from shrimp processing, laboratory studies were conducted (see SECTION VII) on the distribution of suspended and dissolved solids and Chemical Oxygen Demand (C.O.D.) of waste fractions generated in different processing operations. This was done simulating procedures with both old and new style peelers. The former peel raw shrimp after a preliminary aging period and the latter use a rapid steam cook without aging before peeling. It was found that with old style peelers only 60% of the total waste solids and 57.2% of the total waste C.O.D. is recoverable in the shell portion with most of the remainder as solubles in the peeler water. With new style peelers 70% of the waste solids and C.O.D. is recoverable in the shell portion. Apparently the precook reduces soluble losses.

The total C. O. D. in shrimp waste was found to be 0. 21 lbs per lb of live weight for both types of peelers. Five day Biochemical Oxygen Demand (B. O. D.) for the solid portion of shrimp waste approached an ultimate value under laboratory conditions and amounted to 48% of the C. O. D. How rapidly the waste may be consumed under Kodiak Harbor conditions has not been established.

Figure 3 presents 1970 production data for shrimp at Kodiak. The four plants operating in 1970 show roughly the same seasonal variation in pack with a minimum in May, the molting season, and a maximum in July. The monthly average for 1970 was 5. 21 million lbs live weight. For June, July, August and September the monthly average was 7. 20 million lbs live weight. The total for 1970 was 62. 6 million lbs live weight. In 1971 two new processors, one with production about equal to the largest operator for 1970, and another smaller operator entered the field, and a 50% increase in production was planned by one other plant. The projected increase for 1971 is 75% of 1970 production.

From above data the 1971 pollution load from shrimp processing at Kodiak can be calculated at 16. 6 million lbs of C. O. D. or 8 million lbs of B. O. D. per year. Removal of solid wastes would reduce this load by 70%. The remaining 30% solubles are contained in 750 million gals. of process water per year.

Crab Processing

Since the peak of King crab production in 1967, which amounted to about 50 million lbs live weight at Kodiak, this fishery declined to about 9. 7 million lbs in 1970. There has been an increase, however, in the production of smaller species, Tanner and Dungeness crab, with a total for all species of 20. 47 million lbs in 1970 (Table 1).

King crab fishing is now restricted to the period from August through January. Dungeness crab are not fished during the period January through April and Tanner crab production is at a very low level from June through December. In 1970 total crab production showed a high of 3. 58 million lbs per month in September with a low in May of 0. 74 million lbs and June of 0. 73 million lbs.

In 1970 there were nine plants processing crab at Kodiak and these were scattered along the full length of the waterfront. Crab processing differs from shrimp in that the amount of waste generated depends on the type of product. Some of the crab is picked from the shell and marketed as canned or frozen crab meat. Some crab is marketed as whole leg sections in shell and some as frozen whole crab. Data

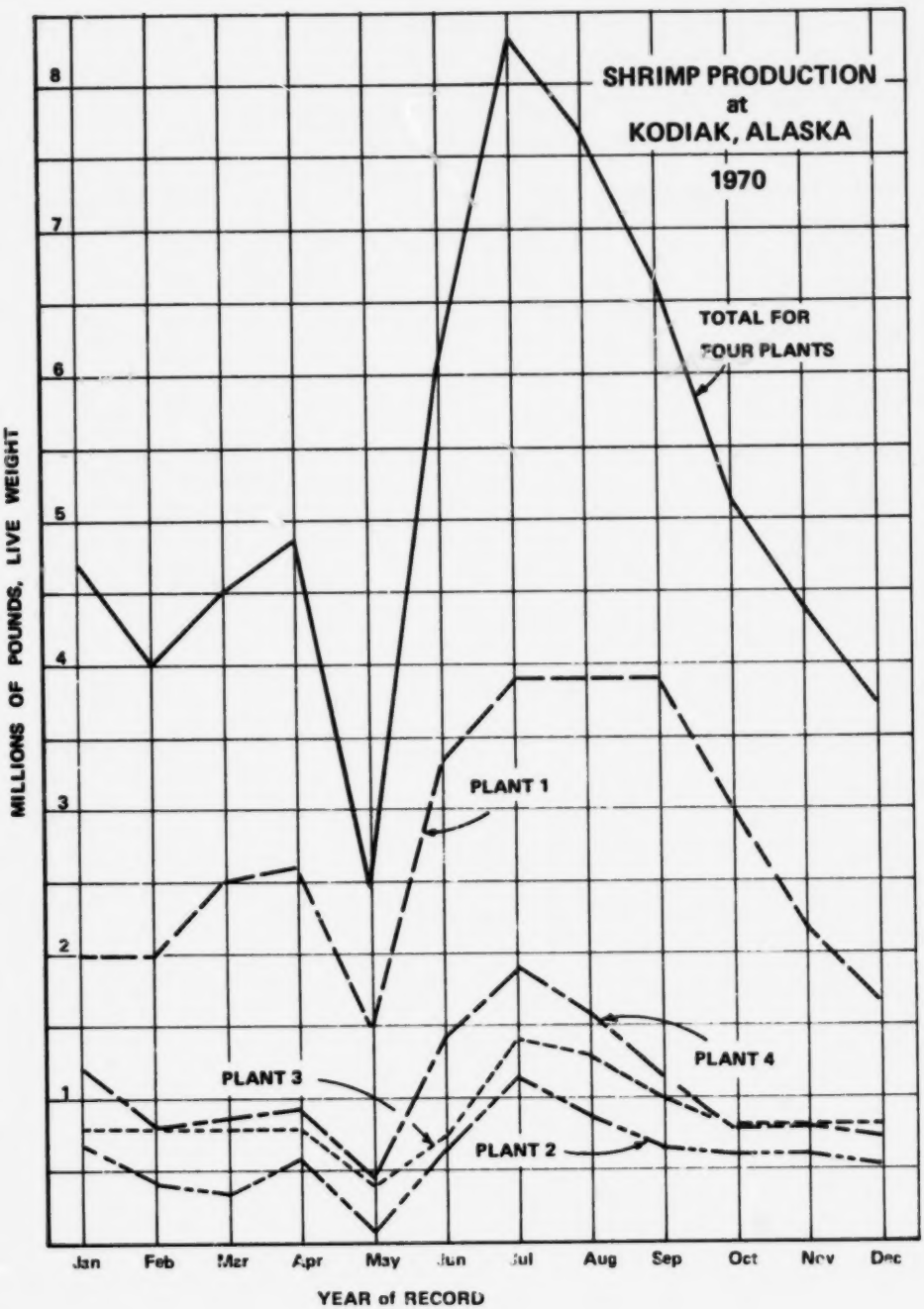

SHRIMP PRODUCTION
at
KODIAK, ALASKA
1970
TOTAL FOR
FOUR PLANTS
PLANT 1
PLANT 2
PLANT 3
PLANT 4
MILLIONS OF POUNDS, LIVE WEIGHT
8
7
6
5
4
3
2
1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
YEAR of RECORD

FIGURE 3

TABLE 1

CRAB PRODUCTION IN 1970 FOR THE KODIAK AREA

Millions of Lbs - Live Weight
(Source - Alaska Department of Fish and Game)

Month	Kodiak Area			City of Kodiak (80%)			
	King	Tanner	Dungeness	King	Tanner	Dungeness	Total
Jan.	1.29	0.71	-	1.03	0.57	-	1.60
Feb.	-	1.21	-	-	0.97	-	0.97
Mar.	-	2.73	-	-	2.19	-	2.19
April	-	1.74	-	-	1.39	-	1.39
May	-	0.76	0.16	-	0.61	0.13	0.74
June	-	0.18	0.73	-	0.14	0.59	0.73
July	-	0.14	1.91	-	0.11	1.53	1.64
Aug.	1.69	-	1.51	1.35	-	1.21	2.56
Sept.	3.69	0.01	0.78	2.95	0.01	0.62	3.58
Oct.	2.47	0.01	0.49	1.98	0.01	0.39	2.38
Nov.	1.73	0.12	0.13	1.38	0.10	0.10	1.58
Dec.	1.22	0.14	0.02	0.98	0.11	0.02	1.11
Total	11.81	7.75	5.73	9.67	6.20	4.58	20.47

from individual plants indicate that in 1970 about 69% of the total crab marketed was as frozen or canned meat, 25% as leg sections and 6% as frozen whole crab. Solid wastes generated by the three different products are 63%, 47% and 1% of live weight respectively.

To determine the total pollution load from crab processing and the amounts of wastes generated in the principal operations of butchering, cooking and picking a series of experiments similar to those on shrimp processing was conducted (See SECTION VII). Live Dungeness crab from Westport, Washington were used for these studies. It is believed that very nearly the same results would be obtained with other species. To simulate different plant practices, some crab were cooked whole before butchering and picking and others were butchered first, cooking only deviscerated bodies and leg sections.

Very nearly the same results were obtained by the two procedures. The total yield of meat was 31% in the first case and 33% in the second compared with an average of about 25% in practice. The total C. O. D. of wastes was 0.16 and 0.14 lbs C. O. D. per lb of live weight for the two treatments. Soluble losses in cooking and picking water were in both cases 12% of the total C. O. D. of the waste. Of this only about 6.7% was cooking losses. This is notably much less than found for shrimp. Backs and viscera account for about 49% to 50% of the total waste C. O. D. and the remainder, 39% is in the shell from the picking lines. Some studies in 1968 on cooking King and Tanner crab showed a similar distribution of solids and presumably of C. O. D. (1).

The total pollution burden, due to crab processing in 1970, may be calculated as follows:

Product		C. O. D. (lbs)
Whole crab	$(20.4 \times 10^6)(0.06)(0.15)(0.067) =$	12,400
Leg section	$(20.4 \times 10^6)(0.25)(0.15)(0.56) =$	430,000
Picked meat	$(20.4 \times 10^6)(0.69)(0.15)(1.00) =$	2,110,000
Total		2,550,000

Of this, over 85% could be eliminated by recovery of backs, viscera and picking line shell.

Salmon Processing

In 1970 there was a very large pack of salmon at Kodiak. It amounted

to about 200,000 48 lb cases of canned salmon and about 2.6 million lbs of frozen salmon (Table 2). The live weight of fish processed per case is about 83 lbs leaving 35 lbs of waste per case. Total waste from canned salmon was thus about 7 million lbs. Since salmon are frozen eviscerated with heads, wastes generated from this source would be about 750,000 lbs in 1970. Total salmon waste was thus about 7.75 million lbs.

As indicated in Table 2 the season extended from June 13 to September 13 with 90% of the production during July and August. There was a pronounced peak from July 12 to August 9 with production averaging 5,000 cases per day and 46,500 lbs per day of frozen salmon for this 4 week period. This would amount to about 185,000 lbs of salmon waste per day.

Salmon are processed at points extending the full length of the waterfront. From the City of Kodiak records water usage is about 1.75 gals. per lb of salmon processed. During the peak season water used for salmon processing would thus be about 830,000 gals. per day. The C.O.D. of screened salmon waste can be estimated as follows:

Representative analysis: solids, 20%; protein, 40% of solids; fats, 30% of solids.

C.O.D. of protein	(0.20)(0.40) 1.35 =	0.104 lb
C.O.D. of fat	(0.20)(0.30) 2.95 =	0.177 lb
Total C.O.D. per lb of drained weight	=	0.281 lb

For the 1970 season this would be 2.2 million lbs of C.O.D. with 50,000 lbs per day during the peak period.

The volume of water associated with salmon packing and the extended distribution of processing plants along the waterfront indicate that complete elimination of the pollution load by collection and processing of both liquid and solid wastes would be impractical at this time. Studies conducted at a salmon cannery operation at La Conner, Washington during the 1970 season indicate (2) that screening (40 mesh screen) of wastes at the processing plants with collection of solids would remove 80% to 85% of the C.O.D. load.

Scrap Fish and Other Fishery Wastes

The principal scrap fish source is small fish caught in the shrimp trawls. These are sorted out prior to peeling and generally amount

TABLE 2

1970 SALMON PRODUCTION AT KODIAK

Week Ending	Cases Packed 48 lbs each	Frozen Salmon lbs
6-13	1,781	-
6-21	1,232	95,280
6-28	17,508	74,664
7-5	789	27,270
7-12	14,774	77,402
7-19	37,838	257,356
7-26	34,835	392,827
8-2	40,006	371,214
8-9	26,714	275,276
8-16	10.612	19,829
8-25	13,131	61,164
8-30	5,314	562,417
9-6	514	-
9-13	-	399,709
Total	205,048	2,614,408

to 3% of the shrimp weight. For the year 1971 this would be 3 million lbs. Other sources, such as herring and halibut trimmings, are of minor significance. Crab butchering waste would probably be collected with scrap fish, but it has already been considered in the previous discussion.

Assuming a C. O. D. load for scrap fish equal to that of salmon waste, the total would be 800,000 lbs of C. O. D. per year.

The Total Pollution Load

In summarizing data for individual sources, indications are that the total pollution burden discharged into Kodiak Harbor as shellfish and fishery wastes in 1971 will be as follows:

	Lbs. C. O. D. /year
Shrimp waste	16, 600, 000
Crab waste	2, 500, 000
Salmon waste	2, 200, 000
Scrap fish	800, 000
Total Pollution Load	22, 100, 000

These figures assume that total shrimp production for the year will be 75% greater than in 1970, and that crab and salmon processing would be about the same as in 1970. The increase in shrimp is based on the number of new peelers and may not materialize in actual production.

SECTION V

PROCESS DESCRIPTION

The Collection System

The dispersion of processing plants, the diverse character of wastes, the seasonal variation of waste generation and the volume of wastes to be handled during peak periods all point to a barging system as the most practical solution to the waste collection problem. Other possibilities such as truck hauling, fluming or pneumatic pipe lines for transport to a processing site have been considered but appear to involve either much greater initial investment or much greater operating cost. It is believed that the load could be handled by a fleet of 12 small barges with 1 work boat for towing to the by-product recovery site. Solid decked barges with bins would be used. Where possible, barges would be spotted at processing plants to collect wastes as generated. Insofar as possible wastes would be segregated into three classes:

1. Shrimp peeler waste.
2. Crab picking line waste.
3. Fishery waste (includes crab butchering waste).

Barges could be compartmented where simultaneous collection of more than one class of waste was needed. Scrap fish from shrimp trawls and crab butchering waste would be collected on a total recovery basis. Salmon wastes would require screening at the processing plants before collection.

It appears likely that the entire barging operation could be contracted to one of the towing companies. Existing small barges could probably be used so that deck bins would be the only investment.

Site Location

Criteria for site location used in the study have been as follows:

1. Availability of land.
2. Adequate size to accommodate recovery plant, fuel and product storage and dock facilities with possible expansion to include secondary liquid waste treatment.
3. Location compatable with collection system to minimize transportation costs.

4. Availability of utilities.

There appeared to be no site along the Kodiak waterfront which would meet all of these criteria. The site which has been selected is at the southern tip of Near Island directly opposite the breakwater at the small boat harbor. This site is owned by the City of Kodiak and is presently unimproved. The available area is ample for the by-product recovery plant and any foreseeable expansion. The topography is reasonably flat with an average elevation of 20 - 45 ft above low tide level. Site improvement costs should therefore be reasonable.

There is water on Near Island which by impounding should be adequate for the by-product recovery plant. If supplementation becomes necessary barge transport is feasible. A diesel generator installation is planned for electric power. Waste heat from the generator would supply a substantial part of heat needed for the protein extraction process.

By-Product Recovery Process

Crab and shrimp shell would be unloaded from barges by pneumatic pipe line. It would be coarsely ground with a hammer mill and passed to continuous alkali extraction units in which the shell proteins would be solubilized and extracted by dilute NaOH passing through the units countercurrent to the shell. Final sections of the units would be used to wash the extracted shell and the NaOH would be added at several points to maintain sufficient alkalinity for complete protein extraction. Average extraction temperature would be 140°F and residence times would be about 2 hours for crab waste and 1 hour for shrimp waste. Laboratory and pilot plant studies indicate that these conditions represent an optimum balance between efficient protein extraction and minimum protein degradation. Other factors such as equipment design, alkali concentration and liquor-to-solids ratio will be of influence in actual plant operation.

The sodium proteinate extract liquor would be clarified and treated with dilute HCl to a pH of about 4.0 precipitating the protein. The slurry of precipitated protein would pass to a centrifuge for dewatering and washing; the washed cake would be dried and bagged.

The extracted shell would be dewatered with a screw press and shipped in bulk to either a Puget Sound port for conversion to chitin and calcium chloride or to Alaska ports for use as a soil fertilizer and liming agent. Burning to yield heat and lime is also possible.

Centrifugate liquor from protein recovery containing 2% to 3% of the C. O. D. of collected wastes would be discharged to harbor waters or ultimately be subjected to secondary treatment.

Fishery wastes would also be pneumatically unloaded and wet ground to a gurry. This would be processed with dilute NaOH in a concurrent unit to dissolve the protein. The treated waste would be screened to remove bone and centrifuged to remove oil. These products would be further processed to meet market requirements. The clarified protein liquor would be neutralized and evaporated to about 50% solids. The product would be similar to the "fish solubles" now produced from fish meal operations.

SECTION VI

POLLUTION ABATEMENT

The collection system and waste processing plan described previously would completely eliminate discharge of solid fish and shellfish wastes into Kodiak Harbor. The effect on the pollution load would be as shown in Table 3.

TABLE 3

POLLUTION LOAD
Lbs per Year

Waste	Total C.O.D.	C.O.D. Removed In Solids	Residual C.O.D.
Shrimp Waste	16,600,000	11,100,000	5,500,000
Crab Waste	2,500,000	2,000,000	500,000
Salmon Waste	2,200,000	1,870,000	330,000
Scrap Fish	800,000	800,000	-0-
Totals	22,100,000	15,770,000	6,330,000

Without secondary treatment of effluents from the protein recovery process, about 2% of the C.O.D. in solid shrimp and crab waste would be discharged as nonprecipitated protein. This would amount to 260,000 lbs of C.O.D. per year. Overall pollution abatement would thus be $\frac{15,770,000 - 260,000}{22,100,000}$ = 70% of the present pollution load. This is essentially all that could possibly be accomplished by elimination of solid waste discharge.

If elimination of the residual 30% of the C.O.D. becomes obligatory, by new Federal and State of Alaska laws, collection and secondary treatment of liquid wastes would be required. Table 4 shows the volume of the water used by processors which would be roughly equivalent to liquid wastes. This would involve an industrial sewer the full length of Kodiak waterfront. Possibly a separate system could be constructed at Gibson Cove.

Also the sewer and treatment plant could be combined with a sanitary sewer system for the City of Kodiak. These possibilities are beyond the scope of the present study. It can be said, however, that the

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TABLE 4

WATER USAGE BY PROCESSORS AT KODIAK
Millions of Gals./Mo

	1969										1970				Total
	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	15 Mo
East Point	13.4	10.6	9.0	18.1	18.1	20.7	17.8 Shrimp Canning Only	12.8	19.0	11.4	19.4	23.2	24.4	28.1	14.1	256.2
King Crab Inc	3.1	11.2	11.8 Crab	11.7	12.0	3.1	1.8 Salmon Canning	6.9	3.8	0	0	0 Herring	0	0	0	70.4
B&B Fisheries	10.2	10.5	10.1 All species	3.3	6.0	8.8	9.3	8.9	5.9	4.9	9.3 Herring	6.2	7.9	9.8	3.0	114.1
Reefer King	0.5	9.2	10.5	5.3	0	1.5	2.9 Mostly Shrimp	1.9	1.6	2.4	10.3	10.8	11.4	11.9	2.7	82.9
Ursin Sea Foods	2.3	1.2	0.2	0.2	0.3	1.9	1.8 Crab	2.0	0.5	2.5	2.4	0.8	2.1	1.0	0	19.2
Princess Roxanna	2.8	4.2	3.3	2.1	3.9	3.0	3.8 Crab	3.2	0.5	3.5	5.6	5.8	11.8	3.3	1.1	57.9
Kinnear & Wendt	8.0	5.6	3.6	7.5	11.0	10.2	7.8 Shrimp freezing and canning	4.0	7.0	4.6	10.0	8.4	9.3	10.3	4.0	111.3
Northern Processors	0	0	0	0.6	2.1	2.8	2.7 All species except Shrimp	1.4	0.2	0.6	0.6	0	0	0	0.2	11.2
Martins King Crab	1.5	1.6	1.2	0.7	0.7	1.0	1.1 Crab	1.1	0.2	1.7	1.8	0.7	1.9	2.4	0.4	18.0
Pt. Chehalis	0.7	1.1	1.8	0.6	3.3	3.8	3.1 Dungeness Crab Mostly	1.5	0.6	1.0	1.2	1.2	1.7	1.6	0.3	23.5
Alaska Packers	0	0	0	0	0	0	5.7 Salmon	6.4	1.2	0	0	0	0.1	0	0	13.4
Columbia Ward	0.1	0	0.1	0.6	1.7	3.2	1.1 Canned King Crab Only	2.1	0.5	0.5	1.1	0.1	0.2	0.1	0.2	11.6
Whitney Fidalgo	2.3	4.2	2.6	0.1	1.5	4.3	3.2 Crab and Salmon	1.7	0.1	0	0	0	1.0	6.4	4.9	32.3
Total	44.9	53.2	53.6	47.0	60.3	73.2	63.4	48.8	44.2	36.9	61.7	57.2	71.8	74.9	30.9	822.0

problem would be insolvable, or at least exceedingly difficult, without prior elimination of solid wastes.

SECTION VII

LABORATORY INVESTIGATIONS

Information presented in this section covers typical experimentation which has been conducted in the laboratories at Seattle, Washington. Much of the data is taken from progress reports submitted during the course of the study. Some data from prior reports is included to illustrate investigative procedures.

Laboratory investigations included protein recovery from King crab butchering waste and King crab picking line waste. Losses in wash water from the screening of crab wastes were measured. Similar investigations were conducted on Dungeness crab picking line waste.

The recoverability of protein from NaOH-protein rich solution by isoelectric precipitation with HCl was investigated.

Factors influencing protein quality and rate of protein extraction from crab and shrimp waste have been investigated. C. O. D., B. O. D. and soluble waste losses have been determined for shellfish waste.

Salmon offal was investigated for protein extraction and solids losses on screening.

Figure 4, a ternary diagram showing approximate shellfish waste compositions, is a useful representation for calculation of changes in extraction operations and comparison of product yields. The point shown for Red crab represents the whole animal. It is not pertinent to the Kodiak situation but illustrates possible application of the protein extraction process in other localities. Red crab is a small pelagic crustaceous species occurring in large swarms in temperate and sub-tropical ocean waters. Harvesting for human food has been proposed (3).

King Crab Butchering Wastes

About 200 lbs of King crab butchering waste were collected by one of the processing plants in Kodiak, frozen and sent to Seattle. Analyses and processing experiments on this material have been conducted.

The material as received (frozen in 30 gal. plastic pails) was very inhomogeneous, consisting of carapaces, gills, blood and viscera, all in unground condition. To obtain an approximate analysis, about

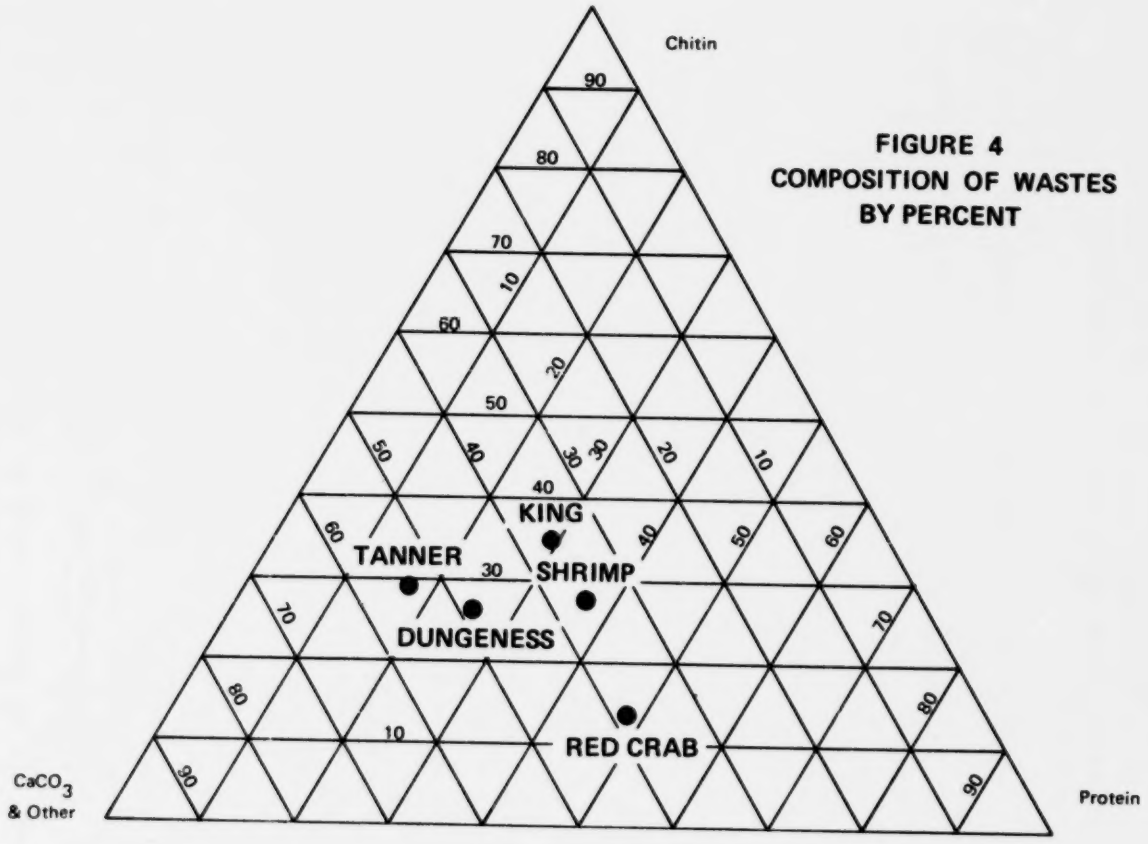


FIGURE 4
COMPOSITION OF WASTES
BY PERCENT

1/2 lb of material was selected, using ratios previously determined from butchering whole crab, to represent the entire waste. This was ground with a measured volume of water in a Waring blender and analyzed with results as follows:

Solids: (corrected for added water)			
26.6		26.1	Average 26.3%
Ash: (dry basis)			
32.4		32.0	Average 32.2%
Nitrogen: (dry basis)			
8.00	7.96	8.06	Average 8.0%
Fat: (dry basis)			
8.17		8.36	Average 8.3%

The probable composition of the waste on a dry basis can be calculated from above data to be:

Ash	32%	Fat	8%
Protein	48%	Chitin	11%

This assumes 6.9% nitrogen in chitin and 15.0% nitrogen in protein.

Previcus studies (4) on crab picking line wastes (all species) have indicated that these materials can be wet-ground to 1/8 to 1/4 mesh and collected on a 40 mesh screen with very little loss (less than 1%) of suspended solid materials.

Two lbs of King crab butchering waste were wet-ground in a Hobart garbage grinder and collected on a 40 mesh screen. Material passing through the screen and solids collected on the screen were separately analyzed with results as follows:

Total Solids:

Retained on 40 mesh	136.0	grams
Through 40 mesh	100.5	grams
Percent through	42.6	%

Fat:

Retained on 40 mesh	1.7	grams
Through 40 mesh	8.8	grams
Percent through	83.7	%

Protein:

Retained on 40 mesh	60.0 grams
Through 40 mesh	62.7 grams
Percent through	51.1 %

B.O.D. of Effluent (estimated from analysis) = 13,000 ppm

It is apparent from the analyses that crab butchering wastes could not be handled in the above manner if a high degree of pollution abatement is to be achieved. Accordingly, an experiment was conducted on the whole waste to determine its behaviour in the alkaline extraction process.

Selected frozen waste, 250 grams [protein = 250(0.263)(0.48) = 31 grams] was mixed with 400 grams of water and ground a few seconds in a Waring blender. A solution of 10% NaOH (79 grams) was then added and the slurry was stirred mechanically at 60°C for 1 hour. The solid matter was then collected on a Buchner funnel. Water and NaOH were again added to the solid residue and it was reextracted at 60°C for 1 hour as before. Solids were again collected and washed. Extract fractions from the treatment were analyzed with results as follows:

<u>1st extract (565 ml)</u>	
Total nitrogen	5.49 mg/ml
Fat	3.75 mg/ml
<u>2nd extract (485 ml)</u>	
Total nitrogen	0.75 mg/ml
Fat	0.02 mg/ml

The solid residue was not analyzed. Protein extracted in the first treatment amounted to:

$$5.49/1000 \times 565/0.15 = 20.7 \text{ grams}$$

and in the second:

$$0.75/1000 \times 485/0.15 = 2.44 \text{ grams}$$

About 90% of the total extracted protein was obtained in the first treatment. The second treatment probably could have been omitted and the residual protein removed by simple washing. Total protein recovery was only 75% of that calculated from the waste analysis. This probably represents nonprotein nitrogen in viscera. Similar

results have been obtained on salmon waste.

Fat removed in the first treatment was 2.12 grams and in the second 0.0097 grams. The first treatment was practically quantitative.

The amount of alkali consumed in the extraction treatment was determined by potentiometric titration of a sample of the first extract. Fourteen ml of 1.0389N HCl were required to the isoelectric point (pH = 4.0) for a 50 ml sample. From this a NaOH consumption of 13.6 lbs per 100 lbs of protein in the waste may be calculated.

Protein recovery by isoelectric precipitation from butchering waste extracts shows lower recovery than from picking line waste extracts. Fat appears to be thoroughly emulsified in the alkaline extract, but may be separable by centrifugation at some intermediate pH between that of the extract (about 13.0) and that at which protein precipitation begins (about 5.5).

Dungeness Crab Protein

During August, 1970, an extended study of the alkali extraction process as applied to Dungeness crab picking line waste was conducted. Nine extraction runs were conducted using three mixer charges with 45 lbs of crab waste per mixer in each run. Each batch was subjected to two extraction treatments using 6.75 lbs of 10% NaOH solution, 0.75 lbs of sodium bisulfite and 50 lbs added water per extraction. The first extraction was at 60° C for 1.5 hours. Following this the extract was drained from the shell, a new charge of 6.75 lbs 10% NaOH and 50 lbs water was added and extraction conducted for 1 hour at 60° C. The second extract was drained to the sewer in these studies since trial experiments showed that its protein content did not warrant recovery in pilot plant operation.

Following the second extraction the shell was washed with water four times in the mixers, drained and refrozen for possible chitin isolation at a later date. The first extract liquor was neutralized to pH 4.0 with dilute HCl to precipitate protein. This was allowed to settle overnight under refrigeration. The supernate, amounting to about 3/4 of the total volume, was decanted and the precipitate was twice washed with water by reslurrying, settling and decantation. The washed precipitate was collected on a Buchner funnel and frozen in bricks 8 x 10 x 2 inches for storage. About 150 lbs of frozen cake were obtained from the nine runs with an average solids content of about 20%. Ash on a representative sample amounted to 1.02%. This material was used for spray

drier performance studies, feeding experiments, and evaluation in pet food formulations.

Recoverability of Protein by Isoelectric Precipitation

Results from earlier experiments in July, 1969, and prior indicated that the solubility of alkali extracted protein at its isoelectric point would be about 5 grams per liter (0.5%). To attain 95% protein recovery would thus require a protein concentration in the extract of 10%. This placed emphasis on the need for countercurrent treatment in order to build up the protein concentration in the extract to the desired level.

Subsequent studies have shown that protein solubility at the isoelectric point (actually, the pH of minimum solubility) is to some degree affected by the severity of the alkali treatment and to a very large degree is a linear function of the salt concentration. Since there is a minimum alkali combining capacity of about 10% for the extracted protein equivalent to about 14.6% of the protein as salt on neutralization, it is not possible to increase the protein concentration without increasing the salt concentration proportionally. One could, of course, consider desalting procedures such as dialysis, reverse osmosis or ion exchange, but these would not be economic in the process. In addition, the added time of treatment to achieve high protein concentrations in the effluent would result in more degradation and more isoelectric protein solubility.

Preceding conclusions point to an extraction process in which alkali concentration, total alkali used and time of contact are all minimized. In recent experiments these objectives have been approached and results have been encouraging. In one experiment an isoelectric protein solubility of 0.25% was attained at a salt concentration of 1.3%. This would amount to a protein recovery of 97.2% from an 8.9% protein solution, assuming minimum alkali consumption.

The use of sodium hexametaphosphate to complex and precipitate additional protein from the supernate as suggested by Mr. John Spinelli (5) of the Seattle National Marine Fisheries Service also shows considerable promise. In one experiment protein solubility was reduced to 0.07% representing a recovery of 96.5% from a 2.37% protein solution.

Factors Influencing Protein Quality

In Table 5 data are presented on amino acid composition of spray dried

TABLE 5

AMINO ACID COMPOSITION
OF SPRAY DRIED SHELLFISH WASTE PROTEINS

	Dungeness crab protein		Shrimp protein		Casein (6)
Sample	As received Basis %	100% protein Basis %	As received Basis %	100% protein Basis %	100% protein Basis
Lysine*	5.4	6.35	6.24	8.34	6.02
Histidine*	2.21	2.60	2.22	2.97	2.31
Arginine*	5.5	6.47	6.04	8.06	2.41
Aspartic Acid	10.3	12.1	6.46	8.63	4.45
Threonine*	3.57	4.20	2.93	3.91	3.81
Serine	2.7	3.18	3.51	4.69	5.88
Glutamic Acid	12.3	14.5	13.3	17.8	21.90
Proline	4.33	5.10	3.40	4.54	15.71
Glycine	4.2	4.94	5.63	7.52	1.16
Alanine	4.6	5.41	5.35	7.14	1.47
Cystine	0.24	0.28	not determined	-	not determined
Valine*	5.5	6.47	4.21	5.62	7.91
Methionine*	1.97	2.32	1.95	2.60	2.75
Isoleucine*	4.7	5.53	3.87	5.17	3.91
Leucine*	6.6	7.78	6.10	8.14	11.07
Tyrosine	4.0	4.70	2.70	3.61	2.72
Phenylalanine*	4.07	4.80	3.78	5.05	5.46
Tryptophan*	1.0	1.18	0.55	0.73	1.00
Total *essential		97.9		104.52	99.94

crab and shrimp waste proteins in comparison with casein (6). It was found that the compositions of the two shellfish waste proteins were quite similar although determined by two different laboratories using different procedures. They both compare favorably with casein in total essential amino acid content. The percentages of arginine and isoleucine are significantly higher for the shellfish proteins while casein shows higher values for valine and leucine.

Feeding tests have been conducted on rats using both the shrimp and crab waste proteins. Both show marked deficiency in sulfur-containing amino acids which can be corrected by supplementation with either cystine or methionine. Otherwise the shellfish waste proteins were found to be equal to casein in nutritional value and there were no toxic effects noted.

A sulfur balance on crab waste and on the extracted protein indicated that most of the sulfur in the waste is still present in the spray dried protein. It should be noted, however, that a very slight odor of hydrogen sulfide has been detected during neutralization of alkaline extracts. Based on assays for cystine and methionine, only about half of the sulfur found in the protein can be accounted for. It thus appears that sulfur-containing amino acids were present before extraction at about twice the level found by assay on the isolated protein.

Review of the literature (7)(8)(9)(10) on effects of alkaline treatment on methionine and cystine in proteins suggests that methionine should be relatively stable in the treatment but that cystine can be largely and irreversibly converted to lanthionine which presumably has no nutritional value as a sulfur source. The exact mechanism for the reaction is not clear but the overall effect is the rupture of disulfide bonds with elimination of 1 atom of sulfur and recombination of residues in a thio ether linkage.

Cystine: $HOOC-CHNH_2-CH_2-S-S-CH_2CHNH_2-COOH$

Lanthionine: $HOOC-CHNH_2-CH_2-S-CH_2CHNH_2-COOH + S$

The form of the eliminated sulfur was not clearly established.

Normally, there is an equilibrium between cystine and cysteine residues in proteins determined by the presence of oxidizing or reducing conditions in the system. The formation of cysteine with free sulfhydryl groups may be an intermediate step in lanthionine reaction. If it is not, or if the sulfhydryl group can be blocked from combining as thio ethers, the presence of a reducing agent should

be beneficial in preventing lanthionine formation. Sulfite ion, either by shifting the equilibrium toward cysteine or by blocking recombination through formation of s-sulfo cysteine groups might serve this purpose.

Experiments by Food, Chemical and Research Laboratories, Inc. indicate that the presence of sodium sulfite during extraction does exert beneficial influences. There were noted in increased extraction rate (rupture of disulfide crosslinks?) and in improved color and odor of the extracted proteins. Analytical results suggest that reduction in extent of cystine destruction may also have been achieved.

Cystine determinations (6) showed 1.05% in Dungeness crab protein extracted in the presence of sodium sulfite and 0.23% in Dungeness crab protein extracted in the absence of sodium sulfite. It would appear that cystine destruction was reduced in the sulfite experiment.

Factors Determining Rate of Protein Extraction

Rate studies have been conducted on extraction of Dungeness crab and shrimp wastes using two different procedures. In one, the rate at which protein concentration approaches an equilibrium value is measured in a batch treatment at constant alkali concentration and temperature. The procedure has been found most useful to characterize the behavior of different wastes and to determine effects of pretreatment, alkali concentration and temperature. Calculation of rate constants assumes that the rate of change of protein concentration at the interface between shell particles and ambient liquid is proportional to a driving force equal to the difference between protein concentration in shell interstices (P_s) and that at the interface (P_i).

$$d P_i/dt = K(P_s - P_i)$$

Further assumptions are that P_i is equal to the protein concentration in the ambient liquid and P_s is equal to the total unextracted protein dissolved in a constant interstitial volume equal to the water content of the moist shellfish waste. Values for P_s can thus be calculated from those for P_i and numerical integration can be employed to obtain the rate constant. This is equal to the slope of the line: $\log_{10}(P_s - P_i)/P_{s(original)}$ versus time. Typical data plots are shown in Figure 5 for shrimp and Dungeness crab waste using different extraction conditions.

It was found that both shrimp and crab wastes show an initial period of very rapid extraction amounting to 30% to 50% of the total protein

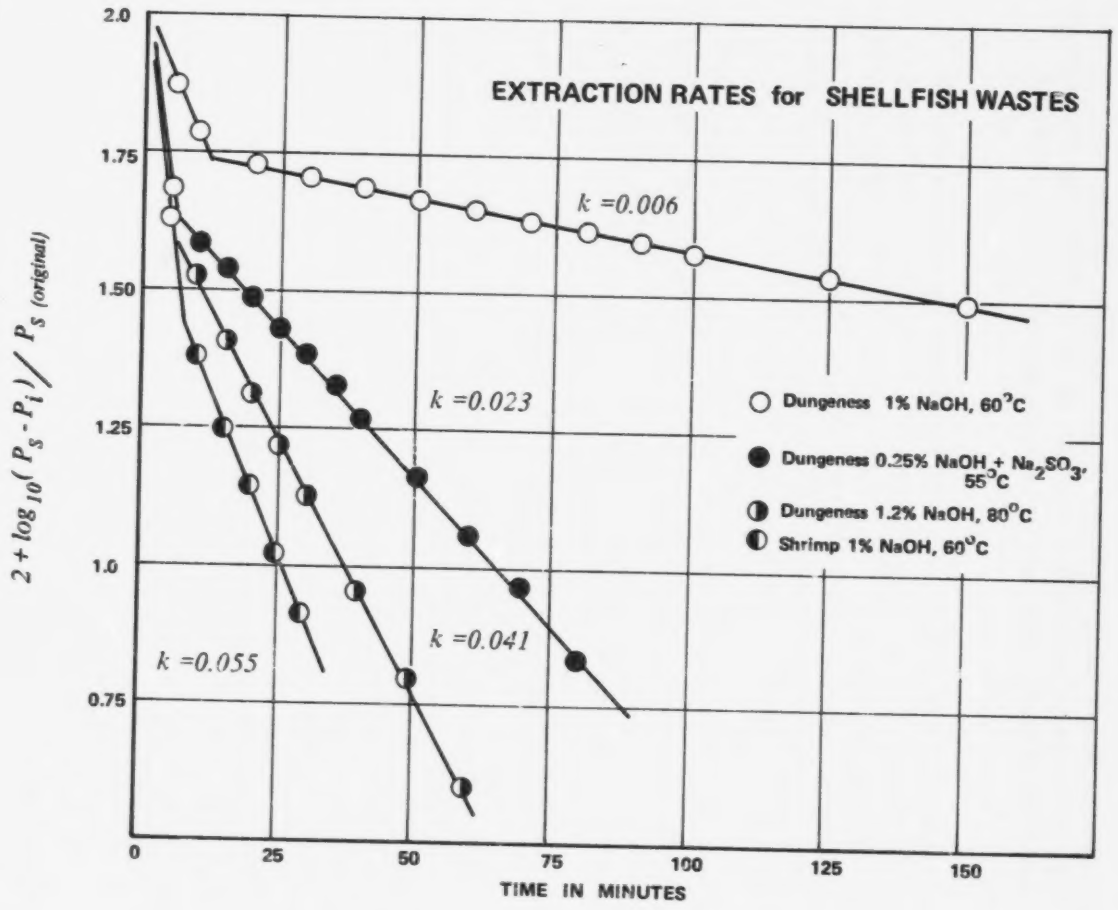

EXTRACTION RATES for SHELLFISH WASTES
2.0
1.75
1.50
1.25
1.0
0.75
0
25
50
75
100
125
150
TIME IN MINUTES
2 + log10 (PS - Pi) / PS (original)
k =0.006
k =0.023
k =0.041
k =0.055
Dungeness 1% NaOH, 60°C
Dungeness 0.25% NaOH + Na2SO3, 55°C
Dungeness 1.2% NaOH, 80°C
Shrimp 1% NaOH, 60°C

FIGURE 5

followed by a rather sharp break and a slow extraction period which fits the diffusion mechanism outlined above. This is undoubtedly an oversimplification of the true mechanism, but serves to give a numerical index of the waste behaviour. It is noted that rate constants obtained for shrimp waste are considerably higher than for Dungeness crab shell particles of the same size, probably reflecting the density of the shell. It is also noted that temperature effects are higher than would be expected for strict diffusion dependence of the rate constants. Note: Curves for Dungeness crab in 1.0% and 1.2% NaOH in Figure 5 are at nearly equal alkali concentrations but with 20° centrigrade difference in temperature. This suggests chemical activation such as rupture of bonds between chitin and protein as being involved in the process. Based upon pilot plant extraction runs alkali concentration does not appear to be an important variable. Sufficient alkali to satisfy the base binding capacity of the protein is necessary. This appears to be about 10 grams of NaOH per 100 grams of protein. Also a pH level of 12.5 or higher appears necessary for the extraction since sodium carbonate solutions with concentrations up to 5% are relatively ineffective. Addition of sodium sulfite to the alkaline extraction liquor may have a specific effect in increasing the extraction rate as well as other beneficial effects.

The other procedure for study of extraction rates has been the determination of protein levels in elution from percolation experiments in a fixed bed diffuser type reactor.

Results from this type of experiment are more difficult to interpret because more variables have to be considered such as flow rate and alkalinity. Alkalinity is not constant during the extraction because unextracted protein absorbs alkali during early stages of the experiment. A mathematical analyses of the elution process has been developed (11)(12) which allows prediction of elution rates from rate constants determined by the "approach to equilibrium" procedure. The treatment would be generally applicable to any fixed bed extraction process which is diffusion controlled and may prove to be of value should such types of processing become indicated.

C.O.D. and B.O.D. of Shellfish Wastes

In previous reporting, C.O.D. values for wastes were estimated for chemical compositions assuming theoretical values for combustion of fat, carbohydrates and protein. It is of interest to compare these with values determined by the usual dichromate oxidation procedure (13).

C. O. D. values were obtained on samples of shrimp waste, crab waste, chitin isolated from shrimp waste by alkali and acid extraction and protein isolated from crab waste by alkali extraction and isoelectric precipitation. Data are presented in Table 6.

Values found are somewhat higher than those used in earlier reports. They would indicate an even higher present pollution load to the harbor but do not significantly affect estimates of abatement by the by-product recovery process.

While C. O. D. values give a measure of the oxygen consumed in complete oxidation of organic matter it is of interest to determine the actual extent and rate of organic breakdown by micro-organisms.

Normally, B. O. D. values are determined by 5 day incubation of very small waste samples in water with added mineral nutrients seeded with micro-organisms normally present in receiving waters. The loss in dissolved oxygen is determined for the 5 day period and is taken as a measure of the oxygen consuming capacity of the waste sample.

With solid shellfish wastes there is no a priori reason to assume that wastes would be entirely consumed in 5 days. The organic matter (chitin and protein) is distributed throughout a more or less dense shell matrix which may be only slowly attacked by micro-organisms. Further, the digestion of chitin requires special enzyme systems (chitinases) that may not be present in predominating micro-organisms.

To investigate some of these factors, studies of the rate of oxygen consumption by shrimp and crab shell have been conducted. To permit use of larger samples and minimize variation due to their heterogeneous character, experiments were conducted using 5 liter volumes of seeded dilution water and about 200 mg solid waste. Dissolved oxygen in the closed system was determined at several elapsed times up to 120 hours. A Yellow Springs Instrument Company Model 54 Oxygen Meter was used.

Results are presented in Figure 6. For comparison, weights of waste used are shown on a dry basis. With 52 mg of shrimp waste the rate of oxygen consumption is very low at 120 hours.

The dissolved oxygen consumed was (8. 5 - 3. 9) (5) equal 23. 0 mg for (52) (0. 68) = 35. 2 mg of chitin plus protein. This would be a 5 day B. O. D. of 23/35. 2 = 0. 653 mg 0_2 per mg of organic matter or 48%

TABLE 6

C.O.D. VALUES OF SHELLFISH WASTE

Sample	Weight mg	Solids %	$CaCO_3$ dry basis %	Chitin+Protein dry basis %	C.O.D. mg 0_2/mg Organic Matter
Shrimp Waste	101	25.9	32.0	68.0	1.27
" "	110	25.9	32.0	68.0	1.42
" "	101	25.9	32.0	68.0	1.44
				Average	1.37
Crab Waste	109	67.5	50.0	50.0	1.03
" "	101	67.5	50.0	50.0	1.12
" "	112	67.5	50.0	50.0	1.05
				Average	1.06
Shrimp Chitin	19.5	93.1	< 1.0	100.0	1.22
" "	27.0	93.1	< 1.0	100.0	1.24
" "	20.5	93.1	< 1.0	100.0	1.27
				Average	1.24
Crab Protein	10.2	100.0	< 1.0	100.0	1.40
" "	10.2	100.0	< 1.0	100.0	1.40
" "	10.2	100.0	< 1.0	100.0	1.37
				Average	1.38

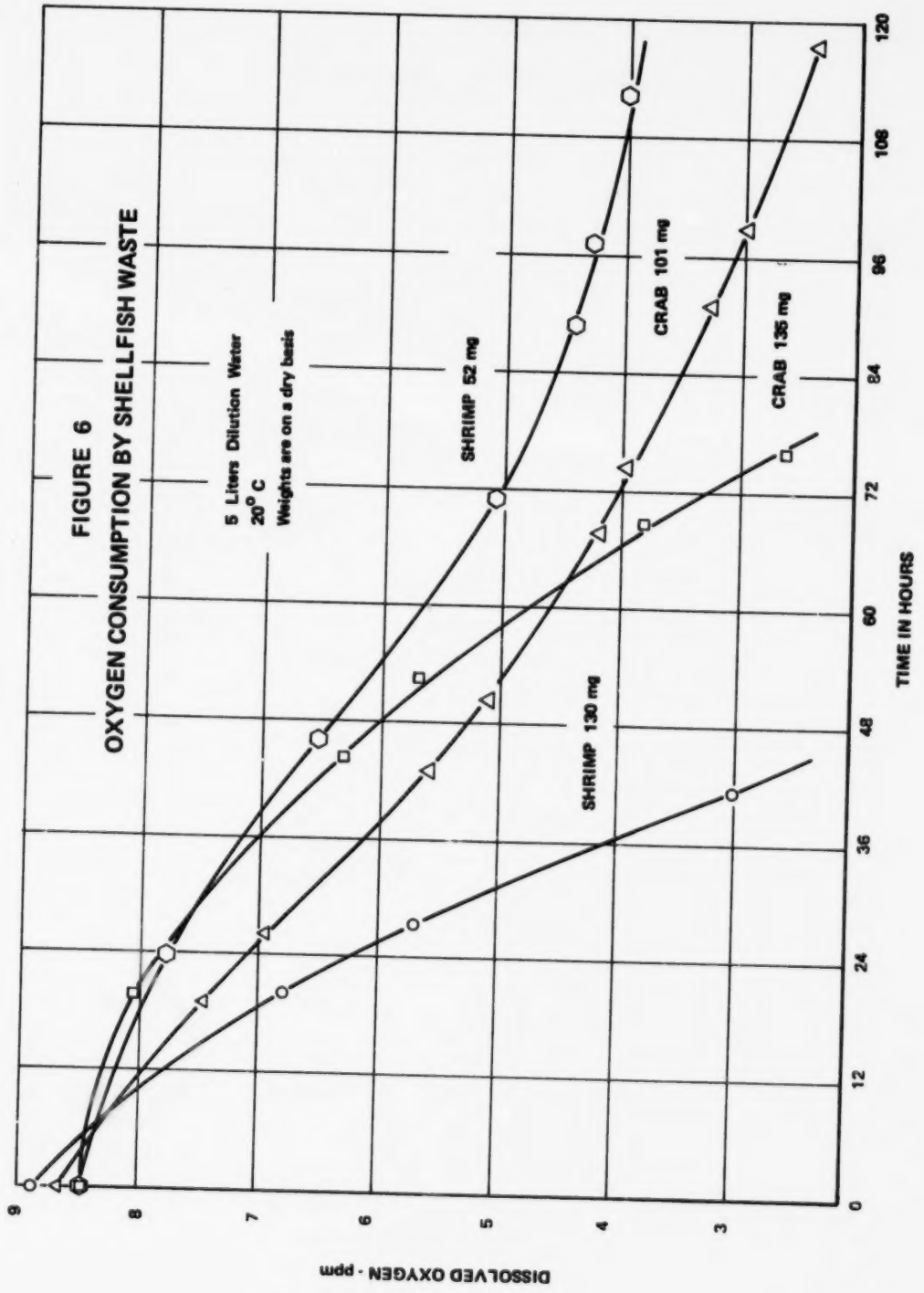


FIGURE 6
OXYGEN CONSUMPTION BY SHELLFISH WASTE
5 Liters Dilution Water
20° C
Weights are on a dry basis
SHRIMP 52 mg
CRAB 101 mg
CRAB 135 mg
SHRIMP 130 mg
DISSOLVED OXYGEN - ppm
TIME IN HOURS
0
12
24
36
48
60
72
84
96
108
120
3
4
5
6
7
8
9

of the C. O. D. ratio in Table 6.

With 101 mg of crab waste some oxygen was still being consumed at 120 hours. The 5 day B. O. D. would be (8.70-2.35)(5) equal 31.8 mg for 50.5 mg of chitin plus protein or 0.63 mg 0_2 per mg of organic matter. The ratio of B. O. D. to C. O. D. would be 0.59.

Soluble Waste Losses in Shrimp and Crab

Fresh raw shrimp obtained from Kinnear and Wendt in Kodiak on March 9, 1971, were frozen and sent to the Seattle Laboratory by air for immediate processing.

In one experiment following practice with old style (Laitram Model A) peelers, 4.0 lbs of thawed raw shrimp were peeled by hand using 4.25 lbs of water for waste preparation. The recovered meat was boiled 2 minutes in water, cooled in water and collected on a 40 mesh screen. Cooking and cooling waters were combined. The solid waste was washed by slurrying twice in water and draining on a 40 mesh screen. The shell wash water and original peeling water were combined. Weights, total solids, suspended solids, C. O. D., B. O. D. and nitrogen were determined on significant fractions and material balances were computed. Data are shown in Table 7.

The yield of picked meat was 24.1% of live weight which is higher than usually obtained with mechanical peelers (18%). B. O. D. and C. O. D. values on peeling and wash water and cooking and cooling waters were very high, reflecting the use of only 0.5 gals. of total processing water per lb of raw shrimp as opposed to about 7.5 gals. per lb of shrimp as an average of operating practice at Kodiak. This suggests that considerable reduction in water consumption might be affected by more efficient peeler design.

The percent of the waste solids recoverable in washed shell was only 60% (57.2% of the C. O. D.). A surprisingly high loss of waste solids (28.7%) and of C. O. D. (33.1%) occurred in peeling and washing water. This should be compared with results obtained on shrimp which were steamed 2 minutes before peeling.

The shrimp were steamed 2 minutes before hand peeling. Shell and process waters were handled as in the previous experiment. Data are presented in Table 8.

The yield of meat was 25.8% of the live weight, again showing improvement over mechanical peeling. C. O. D. and B. O. D. values

TABLE 7

WASTE DISTRIBUTION IN SHRIMP PROCESSING

A. Raw Peeling

Analysis

Sample	Weight grams	Total Solids %	Suspended Solids %	C.O.D. ppm	5 Day B.O.D. ppm	N ppm
Raw shrimp	1,815	25.7		304,000		
Washed shells	1,292	18.3		173,000		
Cooked meat	439	19.8		267,000		
Cooking and cooling water	1,046	4.26	0.43	36,300	18,000	5,850
Peeling and washing water	6,248	1.81	0.49	23,900	9,800	2,180

Distribution

	Solids			C.O.D.	
		total	waste		waste
Sample	grams	%	%	grams	%
Raw shrimp	467	100		552	
Washed shell	236	50.5	60.0	224	57
Cooked meat	87	18.6		117	
Cooking and cooling water	44.5	9.5	11.3	38	10
Peeling and washing water	113	24.2	28.7	130	33

TABLE 8
WASTE DISTRIBUTION IN SHRIMP PROCESSING

B. Peeling after Steaming

Analysis

Sample	Weight grams	Total Solids %	Suspended Solids %	C.O.D. ppm	5 Day B.O.D. ppm	N ppm
Raw shrimp	1,818	25.7		304,000		
Washed shells	1,325	20.1		173,000		
Cooked meat	470	21.4		267,000		
Cooking and cooling water	2,563	1.58	0.37	19,200	9,600	2,500
Peeling and washing water	5,865	1.24	0.63	17,500	7,800	1,680

Distribution

	Solids			C.O.D.		
Sample	grams	total %	waste %	grams		waste %
Raw shrimp	467	100		505		
Washed shells	267	57.2	70.2	254		70
Cooked meat	101	21.6		136		
Cooking and cooling water	40.5	8.7	10.7	34		10
Peeling and washing water	72.8	15.6	19.1	84		23

for process waters were considerably lower than for raw peelings. Total soluble losses were 30% of the initial solids as compared with 40% for raw peeling. It appears that the initial steaming coagulates and prevents loss of some solubles. In this experiment 70% of the initial solids or C. O. D. was recovered in the washed shell.

Three whole live Dungeness crab were brought to the laboratory from Westport, Washington. They were cooked 15 minutes in 2 liters of water using 50 grams of salt. The cooked crab were drained hot, then cooled in a refrigerator and weighed. After cooling, the crab were butchered and weights of different portions were determined. These were then analyzed for solids, C. O. D. and other factors. Data are presented in Table 9.

The yield of picked meat amounted to 31. 2% of live weight which is higher than normal plant practice. Total solids recovered, in all fractions, after correction for added salt, amounted to 27. 2% of live weight indicating full recovery. Solids in waste fractions amount to 74. 6% of the total with only 2. 4% in picking wash water. The remainder would be recoverable either as butchering waste to be processed with scrap fish or as shell.

C. O. D. values as lbs per 100 lbs live weight for backs and picking line shell have been calculated from previous experimental data reported in Table 6. Values for other waste fractions are calculated from present data. The total C. O. D. load in all waste fractions amounts to 15. 8 lbs of C. O. D. per 100 lbs of live weight. Of this, 5. 9 lbs or 37. 4% would be recovered as picking line shell and 7. 9 lbs or 49. 8% as backs and viscera. The remainder 2. 0 lbs or 12. 8% would be lost in cooking and wash water.

Preceding data indicate that pollution abatement from crab processing by recovery of shell and viscera is considerably more effective than collection of solids in shrimp processing. Parallel experiments on King and Tanner crab have not been conducted but there is no reason to expect that significantly different values would be obtained.

In another experiment, 3 Dungeness crab were butchered live and only legs and bodies were cooked. Data for this experiment are presented in Table 10. They are in substantial agreement with the whole cooked crab experiment. Solids recovered were 27. 5% of live weight. Total C. O. D. of waste was 15. 35 lbs C. O. D. per 100 lbs of live weight of which 13. 54 lbs or 88% is recoverable in backs, viscera and picking line shell.

TABLE 9

COOKING WHOLE CRAB

Sample	Live Weight grams	Cooked Weight grams	Total Solids %	C.O.D. ppm	Solids grams	Solids % of total	C.O.D. lb/100 lbs Live Weight
Whole crab							
No. 1	1,090	982					
No. 2	1,045	973					
No. 3	965	900					
Total	3,100	2,855	(27.2% of live weight)				
Legs and Bodies		1,743					
Backs		190	60.2		114.3	13.6	(1.96)
Viscera		530					
Picking Line Shell		615	55.8		353.0	41.8	(5.90)
Leg Meat		563	22.6		127.0	15.1	
Body Meat		404	21.4		86.5	10.3	
Cooking Water		2,150 ml	2.2	13,600	47.3	5.6 (mostly salt)	0.94
Viscera + Wash Water		2,280 ml	6.3	80,400	143.7	17.1	5.90
Picking Water		4,000 ml	0.5	8,400	20.0	2.4	1.08
Total					891.8	105.9	15.78

TABLE 10

LIVE BUTCHERED CRAB

Sample	Live Weight grams	Cooked Weight grams	Total Solids %	C.O.D. ppm	Solids grams	Solids % of total	C.O.D. lb/100 lbs Live Weight
Whole crab							
No. 1	815						
No. 2	923	1,413 (legs & bodies)					
No. 3	980						
Total	2,718		27.5 of live weight				
Backs	183		57.8		106	14.2	(2.07)
Viscera + Water	2,280		5.3	67,200	121	16.2	5.60
Cooking Water		2,520 ml	1.1	7,600	28	3.7	0.70
Picking Waste		540 ml	55.8		302	40.3	(5.87)
Wash Water		4,000 ml	0.3	7,600	12	1.6	1.11
Leg Meat		465	23.3		109	14.6	
Body Meat		322	21.6		70	9.4	
Total					748	100.0	14.35

Salmon Offal

Samples of salmon offal as discharged into Kodiak Harbor by Columbia Ward Fisheries and B & B Fisheries were sent to the laboratories in frozen condition. This material was used for processing studies.

A sample of thawed waste was ground in a home-size garbage disposal unit without added water. The gurry obtained was analyzed for solids, fat, protein and ash. Results were as follows:

Solids	20.6%	(as received)
Fat	30.3%	(dry basis)
Protein	40.0%	(dry basis)
Ash	21.0%	(dry basis)

A mixture was prepared from 1,109 grams gurry, 200 ml 10% NaOH and 691 ml water. This was heated for 1 hour at 60° C with a mechanical stirrer. The solid residue was then collected on a filter, washed with 100 ml of water and dried. Yield 38.8 grams. It consisted of fine bone fragments with a small amount of clam and mussel shells. The extract solution (1,800 ml) contained 8.57 mg nitrogen per ml or 15.4 grams total. This is equivalent to 96.5 grams of protein (N x 6.25) or 100% of that calculated for the starting material.

A 50 ml sample of the extract solution was titrated conductimetrically with standard HCl. It showed an alkali consumption of 18 grams of NaOH per 100 grams of protein. Also, about 37% of the added alkali was unconsumed. Accordingly a second extraction was conducted in the same manner with 0.75% NaOH instead of 1% as used before. Titration of the resulting extract showed a slightly lower alkali consumption per unit of protein with 21.5% of the added alkali unconsumed. Protein in the extract liquor was 107.8 grams or 98% of the initial protein.

Extract liquors were adjusted to pH 4.0 with dilute HCl yielding a good protein precipitation which filtered readily with a clear filtrate.

Additional grab samples of salmon waste collected during the run at Kodiak were sent to Seattle frozen in 3 gal. plastic pails. They varied widely in solids content from nearly 0% to about 21%. A sample containing a maximum of solids was ground in a garbage disposal unit and analyzed for solids yielding 20.7%. The dried material was analyzed with results as follows:

Fat	30.3%
Protein	42.8%
Ash	21.0%
Calcium	3.4%
Phosphate	10.5%

The ground wet material was slurried with 700 ml of 1% NaOH and digested for 1 hour at 60°C using mechanical stirring. It was then filtered yielding 1,800 ml of extract and 38.8 grams of residue (dry weight). The extract contained 53.5 mg protein and 27.2 mg of fat per ml. A material balance for the extraction shows 98% recovery of protein and 70% recovery of fat with 81% of the ash in the dried residue.

The extract was adjusted to pH 4.0 with HCl, to cause isoelectric precipitation of protein, and filtered. Analyses of the filtrate showed the following:

Total volume	2,085	ml
B.O.D.	11,750	ppm
C.O.D.	11,920	ppm
Protein	21.4	mg/ml
Phosphate	800	ppm

Protein recovery by isoelectric precipitation was found to be only 53.5%.

This is much lower than recoveries which have been obtained from alkali extracts of crab and shrimp waste which consistently show 85% to 90% recovery. Attempts to improve recovery by precipitation of a polyphosphate complex or by lime addition were only slightly effective (visual appraisal). It was concluded that autolysis of the waste by action of visceral enzymes was probably responsible. It is also possible that a substantial part of the nitrogen in the filtrate was nonorganic nitrogen. This is supported by B.O.D. and C.O.D. values which are only about 1/2 of values calculated from the assumed protein content.

For comparison with data on Kodiak salmon waste, a sample of waste from a La Conner, Washington operation was subjected to similar treatment.

Analyses of a ground slurry prepared as with Kodiak waste was as follows:

Solids	21.8 % (as received)
Fat	20.4 % (dry basis)
Protein	61.2 % (dry basis)

Thirty two lbs of this waste was extracted with 1% NaOH for 1 hour at 60° C and passed through a 40 mesh screen. Thirty four lbs of extract and washings and 162 grams (dried) of residue were obtained. The residue contained 5.0% nitrogen (31.3% protein) and 62.9% ash. It amounted to only 5.1% of the original solids.

The extract contained 16.3% solids, 110.6 mg protein per ml and 33.5 mg fat per ml. Total recoveries of 88% of original protein and 80% of original fat are indicated. These results probably reflect sampling error since the ground slurry was not homogenous and there should be no losses in the digestion treatment.

Precipitation tests were conducted on small aliquots of the extract with results even less satisfactory than on Kodiak salmon waste.

Experiments on fat removal using a continuous Westplalia separator were more successful. After adjusting to pH 6.0 and passage through the separator the fat content of the extract was reduced from 3.35% to 0.48%. Small scale laboratory centrifuge tests indicated that better separation might have been achieved at pH 8.0.

To summarize results obtained on salmon waste to date, it is concluded that alkali digestion followed by isoelectric protein precipitation or precipitation of protein as a phosphate complex or a calcium proteinate will not achieve a reasonable level of pollutant removal from effluents. The alkali digestion does appear to be of value in homogenizing the waste so that solid residues (bond, etc.) can be removed on 40 mesh screens and so that fat removal can be accomplished by centrifugal treatment. This refining can be conducted at relatively high total solids content (16%) which is not far below that of the dewatered waste (20% to 21%).

Evaporation of the refined extract to about 50% solids using triple effect evaporators would yield a product similar to the "concentrated fish solubles" already an article of commerce. There would be no liquid effluent from the process. The product would be biologically

stable and could be shipped in drums or tanks to market areas.

To estimate the effectiveness of solids removal by screening, recourse is again taken from a La Conner, Washington operation with which we are familiar. This cannery operated during July, August, and September, 1970, primarily on silver salmon. Due to the larger size of these fish only about 68 lbs are processed per 48 lb case as compared with 83 lbs of Kodiak operation on Bristol Bay red salmon. Heads and roe are separated from the waste during butchering and are separately handled for oil and caviar production. Spent heads are hauled to a dump. Remaining solids are collected with a 20 mesh flat type screen and are sold without further treatment for pet food manufacture. Effluent from the screen is discharged into the Swinomish Slough, a tidal estuary, discharging into Padilla Bay or Skagit Bay depending on the tidal flow.

A summary of the season's operations shows the following:

	% of fish (live weight)
Fish packed	71.0
Eggs packed	3.0
Oil produced	0.5
Solid wastes to dump	5.7
Waste sold as pet food	14.1
Waste lost to sewer	5.7

While the waste lost to the sewer was 5.7% of fish processed it was 5.7/29 = 19.6% of the total waste, i.e. of the fish not packed in the can.

SECTION VIII

MARKETS

As the isolation of recoverable by-products from shellfish wastes is a new process the salability of these materials in the quantities anticipated must be considered thoroughly.

The proposed plant will be capable of producing at least 7 million lbs of shellfish protein plus other fisheries products. The shellfish portion will have a protein content of at least 90%, and ash content of less than 5% with the remainder being moisture.

Feeding tests have shown this protein to be of high quality, and exceedingly palatable to pets.

According to one major pet food manufacturer, who conducted extensive feeding tests on cats, it is a preferred protein. This manufacturer has indicated a desire to purchase at least 5 million lbs of the shellfish protein at from $0.12 to $0.20 per lb F.O.B. Kodiak.

As a protein competitive with fish meal, which is the largest volume high grade protein sold, the following comparisons can be made: There were 458,000 tons of fish meal (14) available for sale in the United States during 1970, at an average price of $196.50 per ton for anchovy (65% protein). This is $300.00 per ton ($0.15 per lb) on a 100% protein basis. While 90% protein material calculates to be $270.00 per ton or $0.135 per lb on an equivalent basis, the palatability, low oil and ash content will make the selling price at least $0.15 per lb, with a price floor equivalent to fish meal protein.

Production of 3,500 tons per year of protein will represent 0.8% of the total fish meal available for sale in the United States.

Because of the carotenoid pigment astaxanthin, which gives shrimp and crab their red color, there is great interest in the use of extracted shellfish protein for hatchery trout feed. This pigment when fed to hatchery trout causes their flesh to turn salmon color, a desirable effect. Presently limited quantities of dried shrimp meal are being sold to trout hatcheries for this purpose.

A concentrated supply of protein plus astaxanthin will command a premium price over other protein sources.

A large market exists for food quality shrimp protein. Present selling price for this material is $0.90 per lb on a bond-dry basis. The proposed plant is not being designed to manufacture products for human consumption, however, it is felt that by proper handling certain portions of the waste load can be converted to food grade products provided clearance from the Food and Drug Administration can be obtained.

The use of shellfish protein has not been fully investigated as an industrial chemical.

There are approximately 50 million lbs of soya isolate (90% protein) consumed each year in the United States at a selling price of from $0.22 to $0.24 per lb (15). The paper coating field requires 70% of this market while the paint, adhesive, ink and miscellaneous industries consume the rest.

Limited tests with a regional ink manufacturer have shown that they can replace soya isolate with deoderized shellfish protein. Should this be the case in the paper coating field the potential profit of this plant could rise by 30% to 35%. Further development work must be done to establish these markets.

The markets for salmon oil are well established with fish oil presently selling for $0.1015 per lb. Over 200 million lbs of fish oil were produced in the United States in 1970 (14). Production of 300,000 lbs at Kodiak is an insignificant increase.

The market for fish solubles is also well established. There were 90,700 tons (14) produced in the United States during the first 10 months of 1970. These solubles sold at an average price of $51.90 per ton F.O.B. East Coast plants.

The production of 2,000 tons represent 2.7% of the United States production. Using $30.00 per ton as an estimated selling price F.O.B. Kodiak and an indicated freight cost to Puget Sound ports of $20.00 per ton, the F.O.B. Puget Sound price becomes $50.00 per ton.

Other than a small production of tuna solubles produced at Astoria, Oregon, there are no other local sources of solubles available to Northwest consumers. Northwest consumers import from California, Gulf or East Coast suppliers. The freight to the Northwest from these points would place the product in a preferred price position.

The garden specialty market can readily absorb the 200 tons of fish bone meal which will result from the production of the solubles.

The only other product requiring a market is the 6,600 tons (bone-dry basis) of chitin-$CaCO_3$ complex. Because of the distance between Kodiak and the Continental United States the cost of transportation appears to be a problem. To help resolve this problem this material is to be pressed to 50% solids with a bulk density of 60 lbs per cu ft. Using $10.00 per ton bone-dry basis F.O.B. Kodiak the complex can be shipped to the Pacific Coast ports at a delivered price of $50.00 per ton of solids. This delivered price could make conversion of the complex to chitin and its derivatives economically possible.

There are several companies looking at the possibility of building a plant in the Puget Sound area to convert the complex to chitin derivatives. It is likely that such a plant will be built once a source of raw materials is guaranteed. The Alaska market for the complex exists as a liming agent - soil amendment. Test runs at the Palmer, Alaska, experiment station (16) show that this material is useful on the acid soils of Alaska.

A price of $10.00 per bone-dry tone F.O.B. Kodiak might induce the Alaska agriculturists to use the nitrogen-phosphorous-calcium containing complex on their gardens and farms.

Ready markets for the production of this plant exist at attractive economic returns. Chitin derivatives have huge potential world markets and if made competitive with other soluble polymeric materials can sell in the range of $0.65 to $1.65 per lb. Competitive products are carboxymethylcellulose, polyvinylpyrrolidine, polyacrylamides and others. The markets could be proved if isolation of chitin at Kodiak were possible. Work on this project should be initiated.

SECTION IX

PROPOSED FACILITIES

The proposed facilities consist of: waste collection at the shrimp, crab and salmon processors; transportation of the waste material to the by-product recovery plant; and the by-product recovery plant.

Kodiak has limited sites available for the by-product recovery plant. The sites proposed by Kodiak were inspected. Two sites located in close proximity to the processing plants were too small. A third site located 4 miles from the processors would not permit easy disposal of liquid products produced in the by-product recovery.

The site selected and recommended is located on Near Island directly opposite the shrimp, crab and salmon processors (Figure 7). The by-product recovery plant is to be located on Kodiak city-owned land. The selected site must be no less than 2.5 acres. The site must lend itself to the construction of secondary treatment facilities. The site must be readily accessible for transportation of the waste and recovered products.

Trucking of waste is estimated to be more costly than barging. The use of barges as holding tanks for shrimp waste reduces the investment required for storage of shrimp waste prior to transporting to the by-product recovery plant.

The barging of the waste from the processors to the by-product recovery plant will be handled by long term contract. The barge contractor will supply a minimum of 12 small flat barges and the required power equipment. The by-product recovery plant will supply containers permanently mounted on the barge. The processors will supply the required holding tanks and collection systems within their own plant. The barge contractor will handle the personnel transportation to the Near Island site.

A barge with free draining containers will be located at each shrimp processor. The shrimp processor will pump his wet shrimp waste directly into the barge. The barge will be removed and replaced once or twice a day as production requires. No holding tanks for shrimp waste will be required at the shrimp processing plant.

Crab picking line waste will be dewatered by the crab processor and held in holding tanks adjacent to the barge transfer area. No

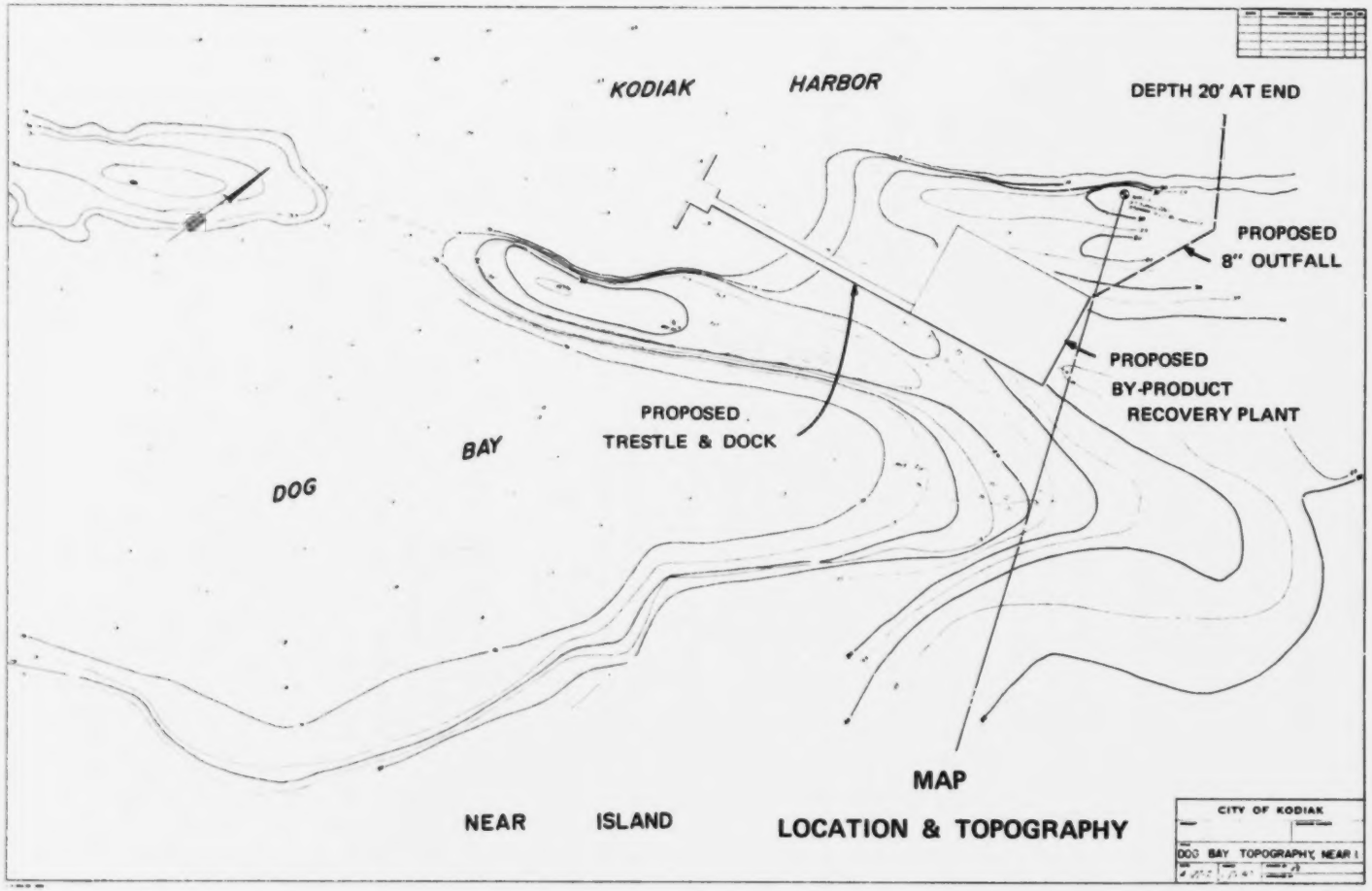

KODIAK
HARBOR
DEPTH 20' AT END
PROPOSED
8" OUTFALL
PROPOSED
BY-PRODUCT
RECOVERY PLANT
PROPOSED
TRESTLE & DOCK
BAY
DOG
MAP
NEAR
ISLAND
LOCATION & TOPOGRAPHY
CITY OF KODIAK

FIGURE 7

significant deterioration of wastes in 12 - 24 hours is anticipated. The holding tank will be emptied by gravity into the barge. Barge pickup will be once or twice a day as production requires.

Scrap fish from shrimp processing and crab butchering waste will be held in holding tanks adjacent to the barge transfer area. Scrap fish, crab butchering waste and salmon fisheries waste may be combined and held in the same holding tank. Pickup will be once or twice a day as required.

A pier and crane will be built at the Near Island site (Figure 8). This pier will accommodate 5 small barges. The pier will be equipped with a 5 ton crane. The pier will accommodate a 3 ton capacity fork lift.

The barges will be unloaded by a pneumatic unloading system. The pneumatic unloading system will transfer the waste from the barges into holding tanks at the by-product recovery plant. A similar system will be used to transfer finished bulk product directly from the by-product recovery plant into cargo vans on barges at the pier.

A 500 KW diesel generator and 600 HP packaged boiler will be located at the recovery plant. These units will use No. 2 diesel as fuel. A plant and instrument air system is included.

The by-product recovery plant will be located in a steel and masonry building 120 ft wide by 180 ft long. The building will be on 2 levels to take advantage of the natural contour of the land. The building will have a concrete slab floor. Within the building are the sanitary facilities, lunchroom, office, laboratory and boiler room (Figure9).

Fresh water for the plant will be obtained from the roof of the building and from a holding pond constructed approximately 300 ft from the building. The water will be treated as required. The liquid effluent from the recovery plant contains less than 5, 000 lbs per day of B. O. D., based on best estimate. The dissolved material is essentially protein. Secondary treatment of the plant effluent is not considered at this time. An outfall to -20 ft should be installed into the more swiftly moving waters of the narrows.

The processing facilities would consist of: a process line for scrap fish, crab butchering waste and salmon fisheries waste; a process line for the shrimp waste; and a process line for the crab picking line waste.

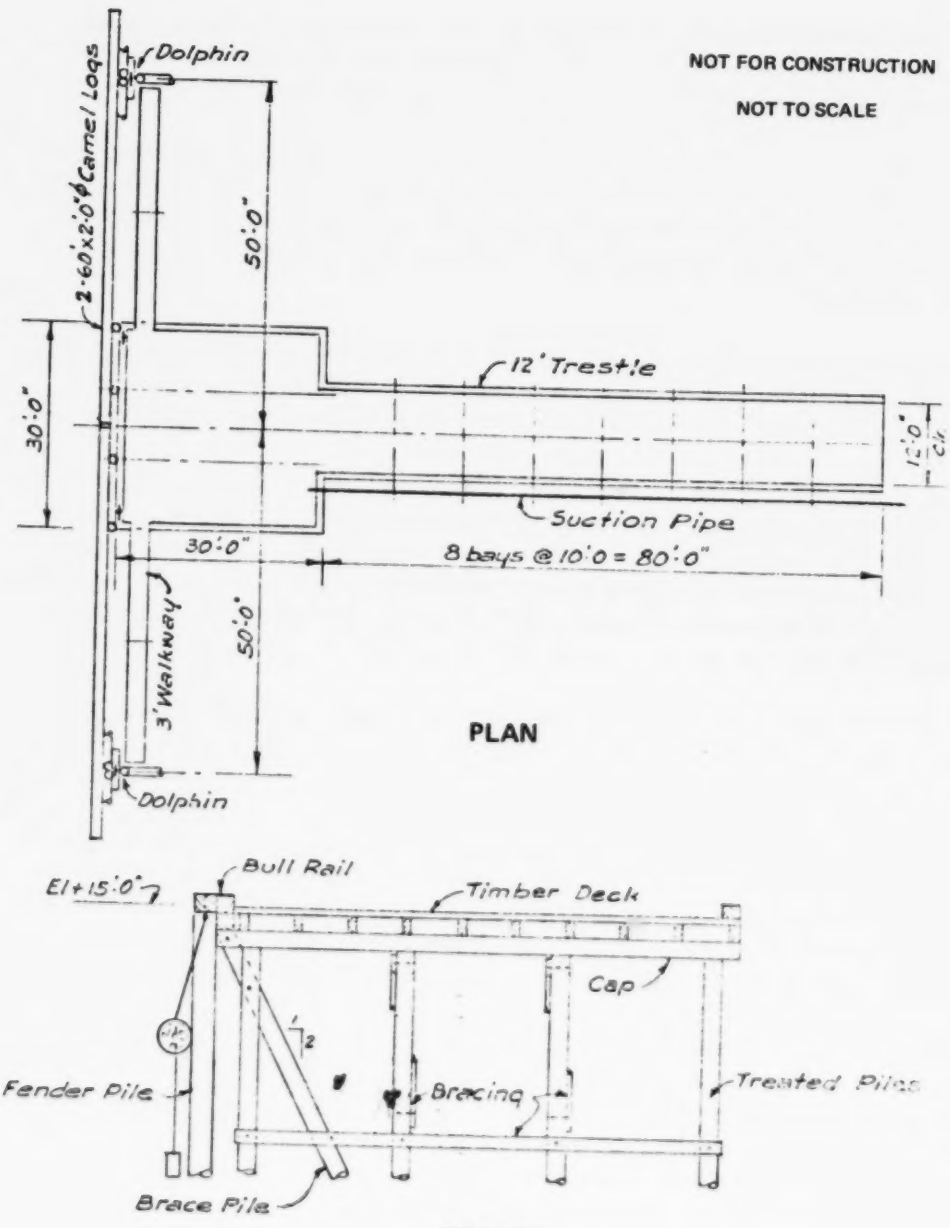
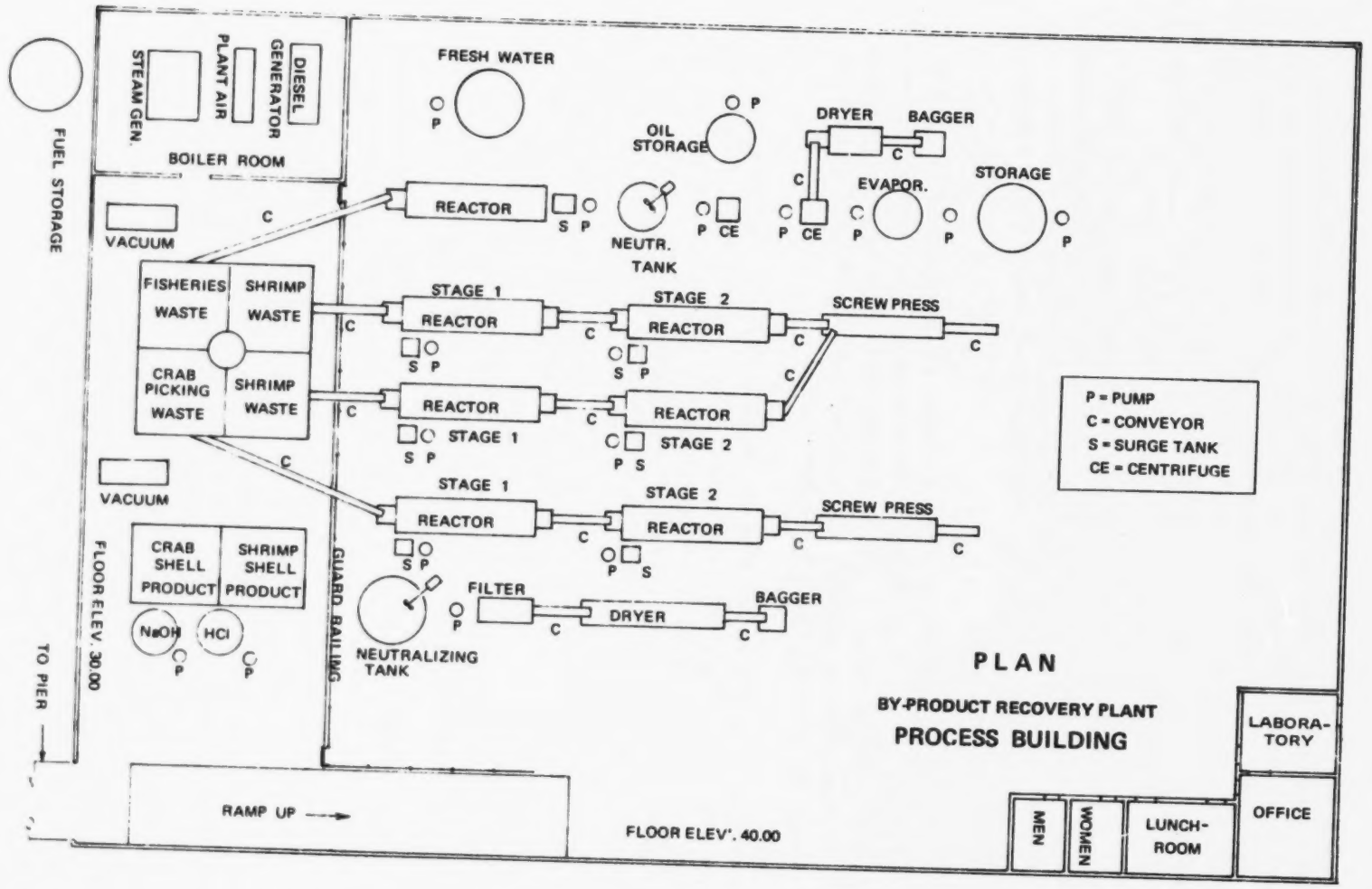


FIGURE 8

DOCK & TRESTLE

FOR THE PROPOSED BY-PRODUCT RECOVERY PLANT



NOT FOR CONSTRUCTION

FIGURE 9

The combined scrap fish, crab butchering waste and salmon fisheries waste will be fed to the process unit from a 12 ft square x 14 ft high tapered bottom tank (Figure 10). A variable rate screw conveyor will feed a grinder. The waste after grinding is conveyed to a 5 ft diameter x 20 ft long cooker where 50% NaOH is added to solubilize the protein. The quantity of NaOH added is equivalent to 1% by weight of solids. The cooker is maintained at 60° C.

The cooker product is pumped to a mixer equipped tank where 31% HCl is added to reduce the pH to 8.5. The pH adjusted waste is centrifuged first to remove the oil and then to remove bone. The oil is collected in drums for shipment. The bone is dried to 6% moisture and bagged for shipment.

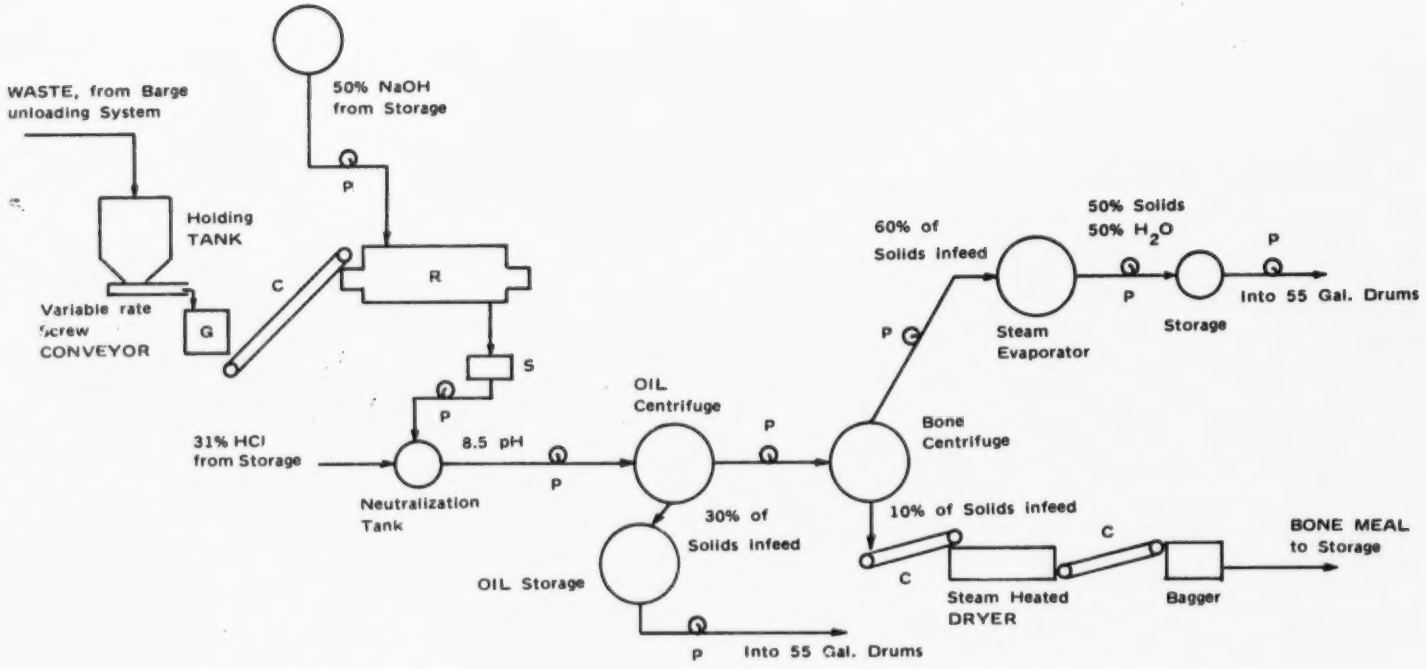
The liquid from the bone centrifuge is reduced in moisture content to 50% in a triple effect evaporator. The 50% moisture material is loaded into drums for shipment. A solids content of 50% has been arbitrarily chosen to equal that of commercial fish solubles. The solids content could be varied to meet trade preferences.

The dewatered shrimp waste will be fed to the process unit from two 12 ft square x 14 ft high tapered bottom tanks (Figure 11). A variable rate screw conveyor at each holding tank will feed a grinder. From the grinders the waste is conveyed to parallel reactors. Each reactor line has two reactors 5 ft diameter x 20 ft long.

In the reactors the waste is treated countercurrently with 50% NaOH. NaOH is added at a rate equivalent to 1 lb of NaOH for each 10 lbs of protein. The contact time in the reactor is about 1 hour. The reactors are heated with steam and the exhaust from the diesel generator. A water wash section is provided within the second stage reactor.

The solids product from both reactor lines is combined and conveyed to a heated screw press where the deproteinized shrimp waste is pressed into a cake with a moisture content of 50%. The pressed cake is pneumatically conveyed either into storage or directly into vans on barges at the pier. Stabilization by removal of protein should permit storage and shipment of the material without significant deterioration.

The NaOH-protein rich solution from both reactor lines is combined with the NaOH-protein solution derived from crab shell and treated in a mixer equipped tank with 31% HCl. The pH is reduced to 4.0 to precipitate protein. The slurry is filtered. The solids are water



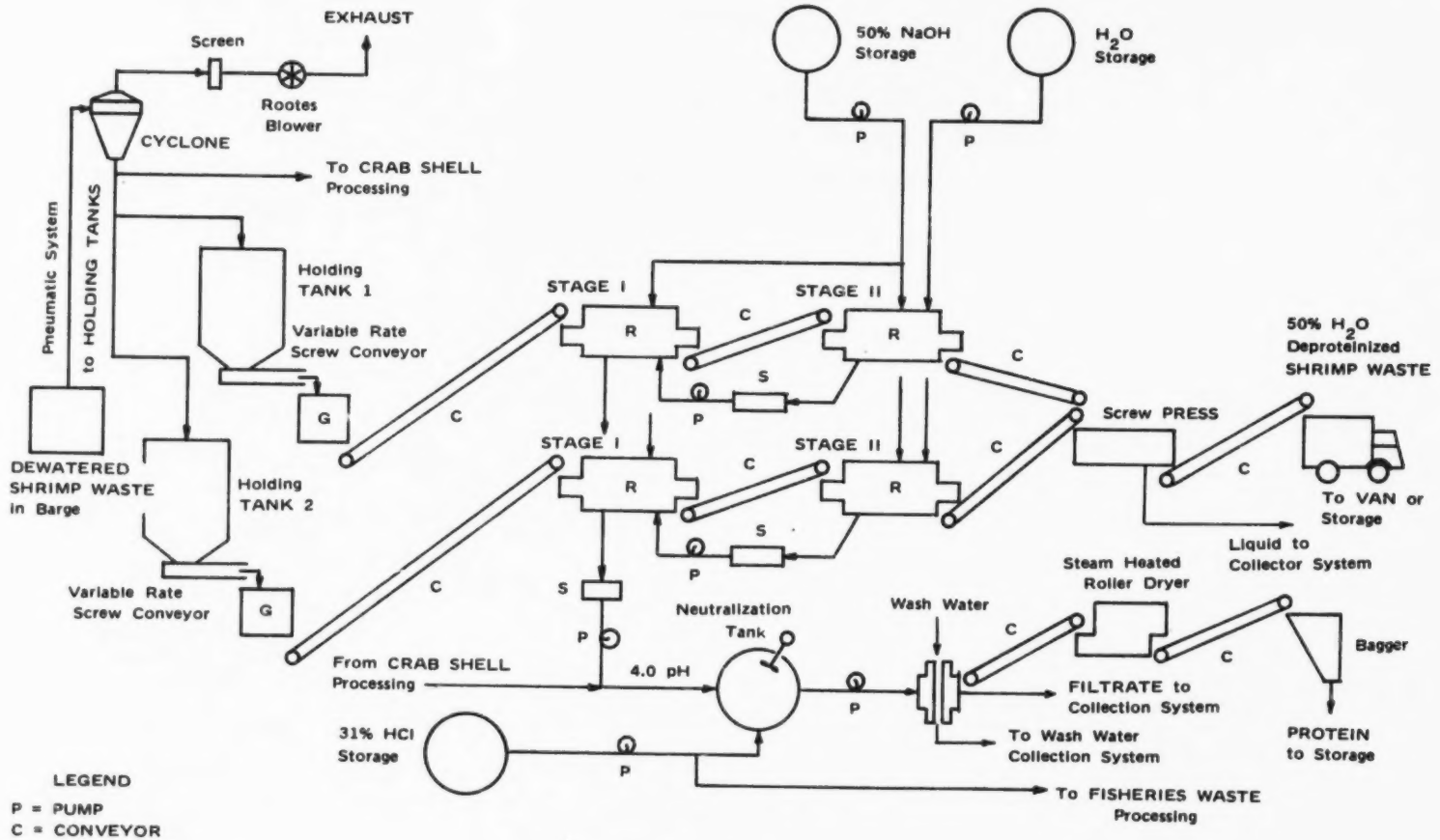
LEGEND
P = PUMP
C = CONVEYOR
S = SURGE TANK
R = REACTOR (COOKER)
G = GRINDER

NOT FOR CONSTRUCTION

SCHEMATIC FLOW DIAGRAM

SCRAP FISH FROM SHRIMP PROCESSORS, CRAB BUTCHERING WASTE
& SALMON FISHERIES WASTE, PROCESSING UNIT

FIGURE 10



LEGEND

P = PUMP
C = CONVEYOR
S = SURGE TANK
R = REACTOR (COOKER)
G = GRINDER

NOT FOR CONSTRUCTION

SCHEMATIC FLOW DIAGRAM

SHRIMP WASTE PROCESSING UNIT

FIGURE 11

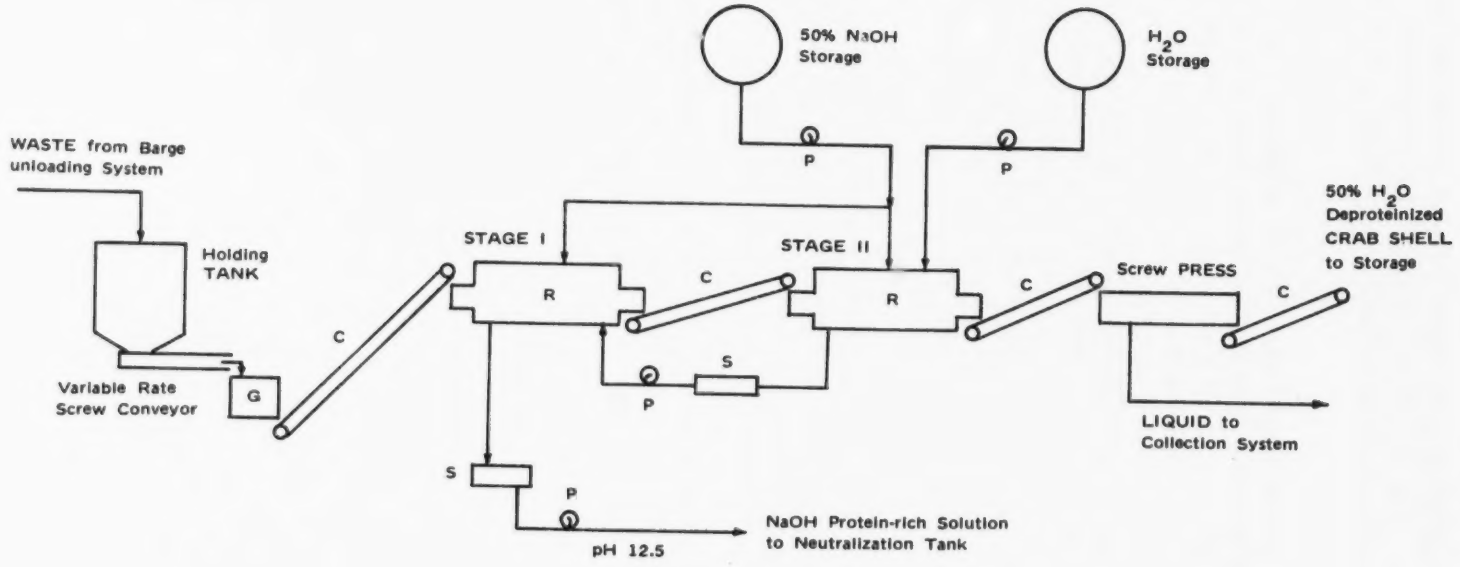
washed and conveyed to a steam-heated roller dryer where the protein is reduced to 6% moisture. Dry protein is bagged for shipment. The filtrate liquid from the screw press is collected and disposed of through the outfall.

The dewatered crab picking line waste will be fed to the process unit from a 12 ft square x 14 ft high tapered bottom tank (Figure 12). A variable rate screw conveyor will feed a grinder. From the grinder the waste is conveyed to the reactor section.

The reactor section consists of two 5 ft diameter x 20 ft long reactors in series. In the reactors the waste is treated countercurrently with an NaOH solution. NaOH is added at a rate equivalent to 1 lb NaOH to 10 lbs protein. The contact time in the reactors is about 2 hours. The reaction takes place at 60°C. The reactors are heated by steam and diesel generator exhaust. A water-wash section is provided in the second stage reactor.

The solids product from the reactors is conveyed to a heated screw press where deproteinized shrimp is pressed into a cake with a moisture content of 50%. The pressed cake is pneumatically conveyed either into storage or directly into vans on barges at the pier.

The NaOH protein-rich solution derived from the crab shell is combined with NaOH protein-rich solution derived from the shrimp waste. The combined steam processing is described in the preceding paragraphs.



LEGEND
P = PUMP
C = CONVEYOR
S = SURGE TANK
R = REACTOR (COOKER)
G = GRINDER

SCHEMATIC FLOW DIAGRAM

CRAB PICKING LINE WASTE PROCESSING UNIT

NOT FOR CONSTRUCTION

FIGURE 12

SECTION X

ECONOMIC CONSIDERATIONS

Based on the 1970 production figures, 13.6×10^6 lbs of shellfish solids could be collected in Kodiak. From this waste load, 8.8×10^6 lbs are shrimp and 3.9×10^6 are crab solids.

However, the number of peelers put into operation when this report was written has increased by 75%. It is assumed in this study that they will operate at the same rate per peeler the others did in 1970. Therefore, there will be at least 15.4×10^6 lbs of collectable shrimp solids available for processing.

Using an average of 38% recoverable protein from shrimp and 30% recoverable protein from the crab, 5.8×10^6 lbs of shrimp protein and 1.2×10^6 lbs of crab protein per year can be recovered by using this process. The indicated market price for this protein is $0.15 per lb F.O.B. Kodiak on a 100% solids basis making the market price for this product $1,050,000.

The salmon waste of 1.3×10^6 lbs would produce 300,000 lbs of oil worth $24,000; 200 tons of bone meal worth $40.00 per ton, or $8,000; and 900 tons of 50% solids salmon solubles worth $30.00 per ton or $27,000.

Crab butchering waste and scrap fish associated with the shrimp trawls of 0.87×10^6 solids would produce an additional 1,600 tons of solubles worth $48,000.

The residual chitin-$CaCO_3$ complex of 6,600 tons (dry) has a minimum value of $66,000 F.O.B. Kodiak for its lime value, and will be worth more when markets open up for chitin as an industrial chemical.

The total worth of these products is $1,223,000 per year.

As it is anticipated that this facility is to be set up along the lines similar to a local improvement district and will enjoy government financing, it therefore is necessary to require the users to pay a fee for waste disposal.

Many different formulae have been proposed for such fees throughout the world. Some are based on B.O.D., C.O.D., or total solids while others are based on water handled.

At Kodiak a reasonable fee should be equivalent to the annual cash reserve required for 7-year depreciation of the plant. The 7-year period was chosen in consideration of the erratic history and uncertainties of the industry and commonly accepted engineering practice for installations of this type. This amounts to $225,000 per year and can be based on the number of pounds of collectable solids handled by the plant at $0.011/lb dry basis.

This is estimated to be 20.6×10^6 lbs, and is summarized on Table 11.

The costs of operating the plant (are as follows and) are based on the barge handling of waste to the Near Island site which will be donated by the City of Kodiak. The direct manufacturing expenses as shown on Table 12 amount to $692,000 per year, and are based on a plant investment of $1,592,000. Table 13.

The indirect expenses amount to $531,000. They are figured on 20-year, 7% bonds, with interest paid at 8% on a $500,000 line of credit, a cash reserve for depreciation of $225,000 per year and consultant and management fees of $99,000.

The estimated profit based on these figures will be $219,700, which is $5,300 less than the disposal fee of $225,000. This means that this $219,700 per year could be returned to the processors paying the dumping fee in its entirety, as adequate provision has been made by means of the cash reserve for depreciation to completely rebuild the entire plant in 7 years or enlarge it as the industry grows.

An alternative use for this money would be to use part of the dumping fee and part of the cash reserve for depreciation to build an industrial sewer system to treat the processing waters not handled by this plant.

All costs estimated for this report are based on June 1971 prices.

TABLE 11

.SALES/YEAR

Shrimp Protein	5.8×10^6 lbs	@ $	.15	= $	870,000
Crab Protein	1.2×10^6 lbs	@	.15	=	180,000
Salmon Oil	3.0×10^5 lbs	@	.08	=	24,000
Fish Bone	200 tons	@	40.00	=	8,000
Fish Solubles	2,500 tons	@	30.00	=	75,000
Chitin-$CaCO_3$	6,600 tons	@	10.00	=	66,000
					$ 1,223,000

INCOME FROM DISPOSAL FEE

Collectible Shrimp Solids					
	15.4×10^6 lbs	@ $	0.011	= $	169,400
Collectible Crab Solids					
	3.9×10^6 lbs	@	0.011	=	42,900
Collectible Salmon Solids					
	1.3×10^6 lbs	@	0.011	=	14,300
				$	226,600
				(Use $	225,000)

Total Income	$1,448,000
Total Costs	1,228,300
Profit Before Taxes	$ 219,700

TABLE 12

YEARLY OPERATING EXPENSES

DIRECT

Barge	$ 132,000
Labor	179,800
Maintenance	50,000
Electricity	30,600
Heat	58,000
Chemicals	152,000
G & A	89,900
	$ 692,300

INDIRECT

Retire bonds 20 years	$ 80,000
Bond Interest 7%	56,000
Sales Costs	31,000
Management	75,000
Consultants	24,000
Op Capital, interest @ 8%	40,000
Cash reserve for depreciation	225,000
	$ 531,000
Total	$1,223,300

Plant Cost

$1,592,000

Operating Credit Line

$ 500,000

TABLE 13
PLANT INVESTMENT - JUNE 1971 PRICES

(Based On 9-Month Engineering Design and Construction Schedule)

NO.	ITEM	DOLLARS	DOLLARS
	Major Process Equipment (all prices delivered Near Island)		
2	Baggers	5,800	
2	Centrifuges	56,000	
20	Conveyors (installed)	31,000	
2	Driers	46,000	
1	Evaporator	28,000	
1	Filter	17,000	
4	Grinders	7,200	
2	Mixers	1,200	
19	Pumps	18,400	
7	Reactors (blenders and cooker)	108,000	
2	Screw Presses	80,000	
17	Tanks and Vessels (erected)	34,200	
	SUBTOTAL		432,800
	Other Major Equipment (all prices delivered Near Island)		
	600 HP Steam Generator with Boiler Feed Water System and Treatment	29,200	
	500 KW Diesel Generator and Motor Control Center	64,500	
	Instrument and Plant Air Compressor and Tank	3,500	
	Water Treating Unit	2,200	
	Pneumatic Unloading, Dried Shell Transfer and Loading System Installed Complete (less wiring)	84,200	
	Dock Crane	2,500	
	Sump Pump for Liquid Waste Collection System	3,500	
	Dust Collection System	10,700	
	Heat Recovery from Diesel Generator	8,000	
	Small Tools (includes 3 ton fork lift and welding equipment)	30,000	
	SUBTOTAL		238,300
	Major Construction Items (Estimated)		
	Building	152,000	
	Pier and Approach Ramp	82,000	
12	Containers for Barges (installed)	54,000	
	Fresh Water Pond and Transmission Line	14,400	
	Liquid Waste Outfall	14,100	
	SUBTOTAL		316,000
	Instrumentation (for those items not included with equipment - installed)		22,000
	Millright (equipment setting)		59,600
	Electrical (labor and materials)		38,800
	Piping (labor and materials)		68,000
	Soils		22,000
	Civil (included with individual items)		
	Painting, Plumbing, Carpentry (included with individual items)		
	TOTAL		1,198,000
	Contingency (15%)		180,000
	Engineering and Construction Management		168,000
	Process Consultants		46,000
	GRAND TOTAL		1,592,000

SECTION XI

PRO FORMA BUSINESS STRUCTURE

The establishment of a pro forma business structure is necessary to implement this study.

It is proposed that an industrial sewage disposal district similar to local improvement districts normally used to build sewer lines and pave streets should be formed using the offices of the City Attorney, City of Kodiak, Alaska.

This district would be composed of the processors, each of whom would have 1 vote, plus the City Manager of Kodiak who would have a vote. They would form a board of directors who would contract with a management firm to arrange the financing, erect the plant and hire the plant personnel and operate the business.

The City of Kodiak would donate the land necessary for the requirements of the plant. With this land the sewage disposal district can borrow the funds required to finance the plant by morgaging the land and the plant.

This money could be obtained through the Small Business Administration, Economic Development Administration, or the Agency of the State of Alaska empowered to make such loans.

The management firm would make recommendations to the board of directors regarding the establishment of dumping fees and other matters concerning the group which would be voted upon by their board.

This district would be formed immediately so that continuity of effort is maintained and the time necessary to build a plant capable of reducing the pollution load to satisfy Federal and State of Alaska laws is minimized.

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SECTION XII

ALTERNATE DISPOSAL METHODS

Handling of the entire industrial waste load by dumping at sea has been mentioned as an alternate possibility.

An economic analysis shows that it would require ocean-going barges and tugs. The 12 barges required plus 1 ocean-going tub have been quoted by experienced towboat operators at $1,500 per day. With 2 tugs it would be $2,000 per day.

Based on a 350-day season, the nonrecoverable costs would be $525,000 per year and $700,000 per year respectively.

Another possibility, the hauling of the waste to a sanitary landfill, has been explored.

There are 50,000 tons per year of wet waste to dispose of.

Trucking costs are $0.20 per ton mile. The present landfill is approximately 6 miles from the waterfront. The trucking costs to haul this waste would be $60,000 per year. The present 120-acre landfill, according to the Kodiak Island Borough Comprehensive Plan (1), states that, "Drainage courses passing through the fill will cause erosion and drainage problems and increase the likelihood that Monashka Bay will be contanimated."

The 50,000 tons of wet proteinaceous waste is approximately 15 times the present waste load and according to recent studies, will cost $3.50 per ton or $170,000 per year to comply with present solid waste management standards.

The cost to the processors in providing the necessary dewater devices and holding hoppers is estimated to be at least $25,000 per plant or $375,000.

The total annual direct cost of sanitary landfill disposal would be approximately $230,000. This figure does not include any costs by the processors for dewatering and holding hopper nor does it include any hauling costs for cover material or treatment of fill leachate.

The third possibility, the welding of a sewer line connecting the processors' plants to a primary treatment plant, is not a part of this

contract. However, in discussions with sanitary engineers, a capital outlay of at least $3,000,000 will be required to treat the 5 million gals. per day of effluent. This does not include the costs of disposing of the 50,000 tons of wet solids captured by the treatment plant.

Considering the above alternate disposal methods it would appear that the by-product recovery method is clearly the most desirable.

SECTION XIII

IN-HOUSE IMPROVEMENTS AT PROCESSING PLANTS

Since the inception of this project, periodic visits by assigned engineering personnel have been made to all seafood processors operating in the City of Kodiak to discuss improvements to their plants that would make waste collection less costly and more efficient.

The more efficient plants use flumed water as the carrying agent for their wastes to a submerged outfall. Others have multiple waste discharges from various points without a common collection system.

The proposed plan for solid waste collection would necessitate elimination of multiple outfalls with all wastes being collected for dewatering and transfer to the barging system. This would facilitate ultimate connection to an industrial sewer system for the remaining liquid wastes.

Another area where in-house improvements were suggested is in economy of water usage. The City of Kodiak does not have an inexhaustible water supply and shortages have been periodically encountered. Some plants do not adjust flow of fluming and washing water with variation of the throughput of materials. During periods of slack operation water consumption per unit of material processed can be excessive. Automatic controls on water lines keyed to instantaneous production rates should be installed where feasible. Automatic shutoff valves on hoses used for wash down were also discussed. In some plants flume sizes are not properly scaled to production rates and arrangements to minimize water needs have not been given proper consideration. With possible increased water rates or liquid waste dumping charges on a volume basis, these factors would be of even greater importance.

SECTION XIV

ACKNOWLEDGMENTS

The assistance of the following persons in furtherance of this project is gratefully acknowledged:

The Honorable Peter Resoff, Mayor of the City of Kodiak, Alaska.

Mr. Rolland Jones, City Manager for the City of Kodiak, Alaska.

Dr. Murray Hayes, Associate Regional Director of the National Marine Fisheries Service of Kodiak.

Dr. Winston M. Laughlin, Research Soil Scientist for the Alaska Agricultural Experiment Station at Palmer.

Mr. John Spinelli, Research Chemist for the National Marine Fisheries Service in Seattle, Washington.

Dr. Sidney M. Cantor, Consultant F.A.O. United Nations, Haverford, Pennsylvania.

Mr. Kenneth A. Dostal, EPA Project Officer, Pacific Northwest Water Laboratory, Corvallis, Oregon.

Also many of the managers and personnel of processing plants in Kodiak have made valuable contributions.

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SECTION XV

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PUBLICATIONS

1. Johnson, Edwin Lee, and Peniston, Quintin P., "Pollution Abatement and By-Product Recovery in the Shellfish Industry," Proceedings of the 2nd Symposium on Food Processing Wastes, Denver, Colorado (March 23-26, 1971)

2. Johnson, Edwin Lee, and Peniston, Quintin P., "Pollution Abatement and By-Product Recovery in the Shellfish Industry," Proceedings of the 26th Annual Purdue Industrial Waste Conference, West Lafayette, Indiana (May 4-6, 1971)

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SECTION XVII

APPENDIX

Analytical Methods and Investigative Procedures

C. O. D. - "Standard Methods for the Examination of Water and Wastewater," 12th edition (1965), page 510, American Public Health Association, Inc., 1790 Broadway, New York, New York 10019.

B. O. D. - 5 Day - "Standard Methods" loc. cit,, page 415.

Solids - Shellfish Waste - 16 hours drying in air oven at 105° C.

Solids - Fish Wastes, Extracts, etc. - 16 hours, vacuum oven, 60° C.

Fat - Ether extraction on dried sample in Soxhlet apparatus.

Ash - Burn at low temperature in platinum. Complete ignition at 600° C in muffle furnace to constant weight.

Sulfated Ash - Ash as above to complete combustion of carbon, cool, moisten with sulfuric acid and reheat in muffle to 600° C.

Calcium - Ash as above, dissolve ash in dilute HCl, add ammonium oxalate solution and slight excess of ammonia. Digest on hot plate until excess ammonia is dispelled. Cool, filter on asbestos pad in Gooch crucible. Wash, transfer to beaker, add dilute sulfuric acid, heat and titrate with standard potassium permanganate solution.

Total nitrogen - Kjeldahl procedure - Sodium sulfate-copper sulfate catalyst. Biuret Protein Analysis, adaptation of Technicon Auto-analyzer procedure N-14b for total protein to permit manual colorimetric tests. Used for protein extraction rate studies. Standardized for each run against specific protein involved using Kjeldahl procedure.

Chitin in Shellfish Waste - Grind 1 gram dry samples to about 1/8 inch mesh. Digest in about 100 ml 2% NaOH at 100° C 1 hour. Filter on medium tared sintered glass crucible. Transfer to beaker and repeat NaOH extraction. Refilter on same crucible. Retransfer to beaker and treat 12 hours at room temperature with 100 ml 5% HCl. Refilter on sintered glass. Wash with hot distilled water until no test for chloride. Dry at 110° C 16 hours and weigh. Check for ash and nitrogen content. Should be less than 1.0% and 6.9% respectively.

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Protein in Shellfish Waste - Determine total nitrogen. Determine chitin as above. Subtract chitin nitrogen from total nitrogen and apply factor. (15% nitrogen in shellfish protein)

Cystine in Shellfish Protein - Protein is hydrolyzed by heating in 6N HCl under reflux for 24 hours. Cystine is determined in the hydrolyzate by Vassel's modification of the Flemming reaction (2).

Protein Extraction Rate Studies - A sample of shellfish waste of desired particle size and known protein content is suspended in distilled water contained in a round bottom flask fitted with a reflux condenser, a mechanical stirrer, a thermometer and a sampling port. The flask is heated by an electric mantle controlled by a variable transformer. When the aqueous sample suspension has attained the desired reaction temperature, a preheated NaOH solution in amount calculated to bring the sample suspension to the desired alkali concentration is quickly added and timing is started. Small samples (3 to 5 ml) of the suspension are withdrawn at noted times. These are immediately filtered and analyzed for protein by the biuret colorimetric procedure (loc. cit.). One or more of the samples are also analyzed by the Kjeldahl procedure for standardization. Extraction rate constants are calculated as described in Section VII, page 35 and 37.

Calculation of Waste Composition - Analytical values for solids, fat, Kjeldahl nitrogen, and sulfated ash or calcium are converted to a dry basis calculating calcium or sulfated ash to $CaCO_3$. The following equations are then used to obtain percent chitin and percent protein.

$$\% \text{ Chitin} + \% \text{ Protein} = 100 - \%\text{Fat} - \% \text{ } CaCO_3$$

$$(0.069)\% \text{ Chitin} + (0.150)(\% \text{ Protein}) = \% \text{ Kjeldahl nitrogen}$$

A nitrogen content of 15% for shellfish waste protein is in better agreement with actual analyses than the usual 16% (Protein = 6.25 x N). Calculated chitin values can be compared with actual yields by isolation.

Pilot Plant Extraction Studies - Wastes are held frozen in a nearby cold storage warehouse. Sufficient waste for a pilot plant run (30 to 90 lbs) is brought to the laboratory and ground with water using a restaurant size Hobart garbage grinder. The ground waste is drained on a 40-mesh stainless screen and transferred to one or more of four small portable cement mixers.

The mixers are externally heated with gas burners. They are equipped with screens for draining and thermometers. They can be operated

singly for batch processing or as a four stage countercurrent system.

The charge to the mixers is made up with calculated amounts of water and 10% NaOH solution to give a desired liquor to solids ratio (usually 6 to 1) and a desired alkali concentration (usually 0.5 to 1.0%). The mixers are rotated and held at the desired temperature (50° C to 80° C) for the desired reaction time (0.5 to 2.0 hours). On completion of the extraction stage, mixers are tilted to drain through screens clamped to the face. Samples of the sodium proteinate liquor are analyzed for protein content (Kjeldahl nitrogen) and for unconsumed NaOH (conductimetric titration). The liquor may be processed for protein recovery by isoelectric precipitation or be advanced to another extraction stage.

Extracted solids are transferred to a Bock laundry reclaimer centrifuge for further dewatering and washing. Samples are analyzed for solids and residual protein. Solids may be advanced without washing to another extraction stage or may be treated for chitin recovery.

1 Accession Number	2 Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM
	05D	

5 Organization
Food, Chemical & Research Laboratories, Inc., Seattle, Washington and Engineering-Science of Alaska, Anchorage, Alaska

6 Title
Pollution Abatement and By-Product Recovery in Shellfish and Fisheries Processing

10 Author(s)
Johnson, Edwin Lee
Peniston, Quintin P.
Braun, F. W., P.E.

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23 Descriptors (Starred First)

Industrial Wastes*, Waste Treatment*, Water Quality Control*, Pollution Abatement*, By-Product recovery*

25 Identifiers (Starred First)

Alaska Fisheries and Shellfish Processing Waste Treatment & By-Product Recovery* Protein recovery by alkali extraction Economics of Treatment*

27 Abstract

Laboratory and pilot plant studies show that utilizable by-products can be obtained from shellfish wastes produced at Kodiak, Alaska. Alkali extraction of the contained protein leaves a matrix of chitin and calcium carbonate. The chitin-calcium carbonate matrix can be converted chemically into its components.

Other fisheries' wastes found at Kodiak; salmon waste and small fish associated with shrimp can be liquified by alkali treatment, partially neutralized with acid, and converted into oil, bone meal and 50% solubles.

The economics and pollution abatement capabilities of the proposed plant are discussed. The construction and operation of this plant would reduce the yearly pollution load from the present 22.1 million lbs per year of C.O.D. being dumped into Kodiak Harbor to 6.6 million lbs per year of C.O.D.

Preliminary designs are submitted for the implementation of this process, together with indicated markets and plan of operation.

Abstractor	Institution
Edwin Lee Johnson	Food, Chemical & Research Laboratories, Inc.

WR 102 (REV JULY 1969)
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